Hornbill Classes

AGRICULTURAL ENGINEERING

TOOL KIT SERIES

UPSC

INDIAN FOREST SERVICE

2026 - 27

Linkage of Concepts with PYQs + Infused with Infographics & Maps

Paper - 1

Section - A

Quick Revision

MPPSC STATE FOREST SERVICE 2023



Shashank Jain
Comprehensive Forestry Course + CIGP



Jyoti Thakur
Comprehensive Forestry Course + CIGP



Shivam Gautam
Comprehensive Interview Guidance Programme



Nitin Patel
Comprehensive Forestry Course + CIGP



Ravi Kumar
Comprehensive Interview Guidance Programme + Test Series



Ankur Gupta
Comprehensive Forestry Course



Deependra Lodhi
Comprehensive Interview Guidance Programme



Kapil Chauhan
Comprehensive Forestry Course



Alok Kumar Jhariya
Comprehensive Forestry Course + CIGP



Tarun Chouhan
Comprehensive Interview Guidance Programme + Test Series



Raghvendra Thakur
Comprehensive Forestry Course + Test S. + CIGP

11 Out of 12 Total Selections in
Assistant Conservator of Forest (ACF) 2023

108 Out of 126 Total Selections in
Range Forest Officer (RFO) 2023



Arvind Ahirwar
Comprehensive Interview Guidance Programme + Test Series



Pushpendra Singh Ahirwar
Comprehensive Forestry Course + CIGP



Narendra Gunare
Comprehensive Interview Guidance Programme + Test Series



Jitendra Kumar Verma
Comprehensive Forestry Course + CIGP



Jaishrish Barethiya
Comprehensive Forestry Course + CIGP



Bhavna Sehariya
Comprehensive Forestry Course + CIGP



Pradeep Ahirwar
Comprehensive Forestry Course + CIGP



Anil Kumar Gour
Comprehensive Forestry Course + CIGP



Aakash Kumar Malviya
Comprehensive Forestry Course + CIGP



Rajesh Kumar Jatav
Comprehensive Forestry Course + CIGP



Veerendra Prajapati
Comprehensive Interview Guidance Programme + Test Series



Dinesh Kumar
Test Series



Niranjan Dehariya
Comprehensive Forestry Course + CIGP



Abhinay Chouhan
Test Series



Sher Singh Ahirwar
Comprehensive Forestry Course + CIGP



Pradeep Jatav
Comprehensive Forestry Course + CIGP



Amit Sisodiya
Comprehensive Interview Guidance Programme



Abhishek Barodiya
Comprehensive Interview Guidance Programme



Golu Goyal
Comprehensive Interview Guidance Programme + Test Series



Pawan Raje
Comprehensive Interview Guidance Programme + Test Series

AGRICULTURE ENGINEERING

MODULE – 1

EDITION : 2026

+917223970423 **Hornbillclasses.com**

Gole ka mandir, Morar, Gwalior (MP) 474005

SYLLABUS

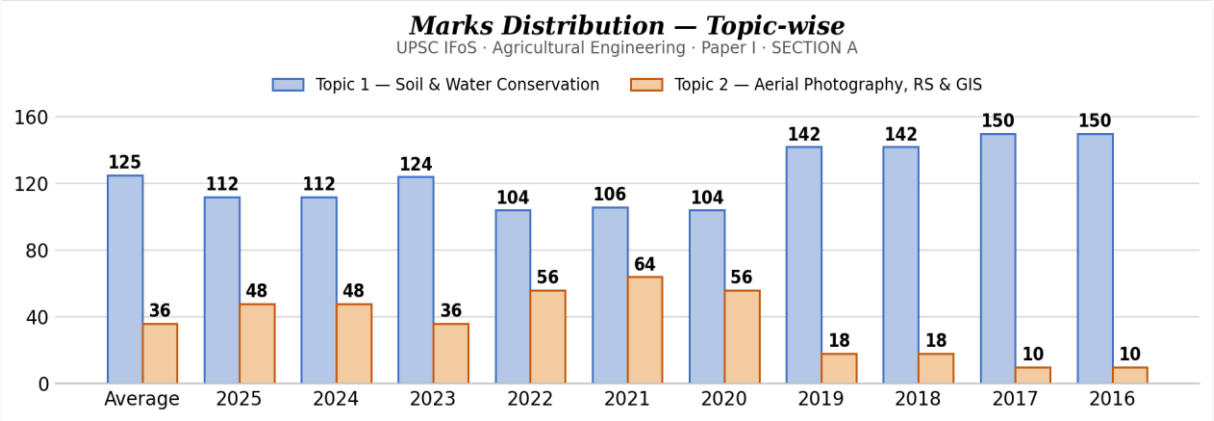
Indian Forest Service (IFoS) [Paper 1 | Section A]	***Soil and Water Conservation*** **:** Scope of soil and water conservation. Mechanics and types of erosion, their causes. Rainfall, runoff and sedimentation relationships and their measurement. Soil erosion control measures — biological and engineering including stream bank protection — vegetative barriers, contour bunds, contour trenches, contour stone walls, contour ditches, terraces, outlets and grassed waterways. Gully control structures — temporary and permanent — design of permanent soil conservation structures such as chute, drop and drop inlet spillways. Design of farm ponds and percolation ponds. Principles of flood control — flood routing. Watershed Management — investigation, planning and implementation — selection of priority areas and watershed work plan, water harvesting and moisture conservation. Land development — leveling, estimation of earth volumes and costing. Wind Erosion process — design for shelter belts and wind brakes and their management. Forest (Conservation) Act. ***Aerial Photography and Remote Sensing*** **:** Basic characteristics of photographic images, interpretation keys, equipment for interpretation, imagery interpretation for land use, geology, soil and forestry. Remote sensing — merits and demerits of conventional and remote sensing approaches. Types of satellite images, fundamentals of satellite image interpretation, techniques of visual and digital interpretations for soil, water and land use management. Use of GIS in planning and development of watersheds, forests including forest cover, water resources etc.

Module - 1

CONTENTS



SN	Chapter	Page No
Soil and Water Conservation		
1.	Soil erosion fundamentals	1 – 19
2.	Soil conservation	23 – 48
3.	Gully control permanent structure	49 – 80
4.	Flood control watershed management, land development	81 – 102
Aerial Photography and Remote Sensing		
5.	Arial photography and remote sensing	103 – 124
6.	GIS application	125 – 133



INDIAN FOREST SERVICE (IFoS) PYQs | 2016 – 2025

Soil erosion fundamentals

2025	• Discuss the major types of precipitation storm. [P1/1(a) | 8M] • Discuss the impacts of soil erosion on water quality. [P1/1(b) | 8M] • Discuss the basic assumptions and steps involved in the development of unit hydrograph. [P1/1(c) | 8M] • Explain the functional relationship of length of slope and degree of slope in the process of soil loss by water erosion. Discuss the methods of estimation of erosivity from rainfall data. [P1/2(a) | 10M] • What are the factors that influence soil erodibility by wind? Discuss the impacts of different types of water erosion. [P1/2(b) | 15M]
2024	• Write a short note on the salient characteristics of precipitation on India. [P1/1(a) | 8M]
2023	• Explain the different processes involved in the development of gullies. [P1/1(b) | 8M] • Determine the peak rate of runoff for a 10-year frequency from a watershed of 250 hectares, having weighted value of runoff coefficient (C) as 0·47. The distance from the remotest point in the watershed to the outlet is 3000 m and the elevation difference between the highest and outlet points of the watershed is 25 m. The maximum intensity-duration-frequency relationship of the watershed is given by i = (6·3117 × T^0·1523)/(D + 0·50)^0·945 where i = intensity in cm/h, T = return period in years and D = duration of rainfall in hours. [P1/2(b) | 10M] • Explain the terms 'erodibility index' and 'roughness factor' used for prediction of wind erosion. [P1/3(a) | 10M]
2022	• Describe isohyetal method of estimating average rainfall depth over an area. Also write the advantages of it over arithmetic mean method. [P1/1(c) | 8M] • What is a unit hydrograph? Write the uses and limitations of unit hydrograph. Explain the method for development of unit hydrographs of different durations by S-curve. [P1/2(b) | 15M]
2021	• Discuss in brief: (i) Sediment delivery ratio (ii) Stream channel erosion. [P1/1(b) | 8M] • Define synthetic unit hydrograph and describe its derivation method. [P1/2(c) | 20M] • Differentiate between the approaches of USLE and MUSLE models for soil loss and comment on their ranges of utility. [P1/3(a) | 10M]
2020	• Define drainage density and derive the relationship between drainage density and ruggedness number. [P1/1(c) | 8M] • Determine the depth of runoff and peak rate of runoff for 25 years recurrence interval for antecedent moisture condition II from a 150-ha watershed. The curve number to apply for three 50 ha sub-watersheds for antecedent moisture condition II are respectively 85, 65 and 75. Six hours, 25 years frequency rainfall for the given location is 120 mm. The time of concentration and time to peak of runoff are 30 min and 60 min respectively. [P1/2(c) | 15M]

	• The normal annual rainfall at Stations A, B, C, and D in the basin are 80·97, 67·59, 76·28 and 92·01 cm, respectively. In the year 1985, the Station D was inoperative and the Stations A, B and C recorded annual precipitation of 91·11, 72·33 and 79·89 cm, respectively. Estimate the rainfall at Station D in that year. [P1/3(b) | 10M] • Discuss the methods of separation of base flow from a runoff hydrograph. [P1/3(c) | 20M]
2019	• Name different soil conservation regions of India with salient soil conservation problems in these regions. [P1/1(a) | 8M] • What is universal soil loss equation? Explain in detail various parameters involved in the computation of soil loss using this equation. [P1/2(a) | 10M] • Explain different methods for measurement of soil losses from agricultural watersheds (use diagrams wherever required). [P1/3(b) | 10M] • Construct a hyetograph from the rainfall data provided in the table. [P1/4(c) | 10M] • Compute the peak runoff rate of 15 years return period from a watershed area of 150 ha to design the field diversion. The sub-watersheds of 50 ha, 75 ha and 25 ha are kept under cultivation (c = 0·5), forest cover (c = 0·3) and grassland (c = 0·3), respectively. The other details are as follows: maximum length of watercourse = 2500 m; relief = 50 m; slope of watershed = 2·5%; watershed soil is clay; values of a, b, k and n are 0·1483, 0·50, 7·176 and 0·9459, respectively. [P1/4(d) | 10M]
2018	• What are the different types of runoff? Explain the factors that affect the runoff in a watershed. [P1/1(a) | 8M] • Discuss the Rational method of predicting design peak runoff rate. In a watershed the most remote point is 600 m away from the outlet point. The outlet point is 3·0 m below the most remote point. Calculate the time of concentration of watershed. [P1/2(b) | 10M] • Explain a procedure for checking rainfall data of a station for consistency. [P1/2(c) | 10M] • The ordinates of the 2-h unit hydrograph of a watershed are given for hours 0 to 22. Determine the ordinates of S-curve hydrograph and using S-curve determine the ordinates of the 4-h unit hydrograph of watershed. [P1/3(a) | 10M] • What are the factors which affect soil erosion by water? Discuss. If the degree of slope is increased 4 times, what will be the relative increase in erosion caused by water? [P1/3(b) | 10M]
2017	• Describe briefly, the SCS-CN method of runoff estimation. A watershed has 100 ha area. The watershed has 20 ha pasture in silty clay soil of 2% slope (CN = 65), 30 ha of pasture on silty loam soil of 0·5% slope (CN = 70) and remaining 50 ha of wheat crop on loam soil of 1% slope (CN = 85). Estimate the weighted curve number for the watershed. [P1/1(e) | 8M] • What are rainfall Depth-Area-Duration (DAD) curves? Write down the step-by-step procedure for drawing Depth-Area-Duration curves. [P1/2(a) | 10M] • Explain in brief, different types of erosion and their causes. [P1/2(b) | 10M]
2016	• What are the main causes of soil erosion in India? Explain the agronomic practices adopted for controlling the soil erosion. [P1/1(a) | 10M]

	• Let P_1, P_2, P_3, …, P_n be the depths of rainfall recorded in n rain gauges enclosed by polygon having areas A_1, A_2, A_3, …, A_n within the watershed. Calculate the average depth of rainfall ($\bar{P}$) in the watershed of area A. [P1/1(c) | 10M] • Define rational formula for estimating peak runoff rate. Why is it called rational? What are the limitations of rational formula? [P1/3(b) | 10M] • What is water-stage recorder? Discuss the current meter as a water flow measuring device. [P1/4(b) | 10M]

Soil conservation measures

2025	• Write down the principles to be adopted while calculating the spacing of bunds (contour and graded bunds). Also, calculate the height of the bunds, if the distance between the bunds is expressed by L, vertical interval between the bunds is expressed by V, width of water spread is expressed by W and land slope is expressed by S percent. Assume the maximum rainfall amount which has to stand behind the bund as 15 cm. [P1/3(c) | 15M]
2024	• State the adoptability and functions of conservation ditches and contour stone wall used for control of soil erosion. [P1/1(c) | 8M] • Discuss in brief about vegetative management and tillage practices used for control of erosion by wind. [P1/1(b) | 8M] • Discuss in brief about the main objectives, their types, limitation in use and precautionary measures to avoid failure of terraces — a soil erosion control measure. [P1/2(b) | 10M]
2023	• Discuss in brief 'wattling — an erosion control measure'. [P1/1(a) | 8M] • Derive the expression for area lost in percentage for cultivation due to construction of bench terrace under the following conditions: (i) Batter slope 1 : 1 (ii) Batter slope ½ : 1. [P1/2(c) | 20M] • Design a grass waterway with trapezoidal cross-section for the following data: (i) Peak rate of runoff, Q = 4·0 m^3/s (ii) Grade to be used = 0·3% (iii) Manning's roughness coefficient = 0·04 (iv) Side slope, Z = 2 : 1 (H : V). Assume other necessary data. [P1/3(b) | 15M]
2022	• Discuss soil conservation farming practices recommended for lands under land use capability classification Class II. [P1/2(a) | 15M] • Calculate the design dimensions of a contour bund in a medium deep soil having an average slope of 3%. The maximum expected rainfall during a 10-year recurrence is 20 cm. The infiltration capacity of the soil in the area is such that 30 percent of the rain infiltrates into the soil. The horizontal interval between bunds is 60 m. Assume slope of seepage line to be 4 : 1 and side slope of bund to be 1·5 : 1. [P1/2(c) | 10M] • A 200 m long graded bund is laid out at a slope of 0·4%. The height of the graded bund having trapezoidal channel was measured to be 45 cm. The bottom width of the

	channel was 2 m and the side slopes were 5 : 1 each. Determine maximum runoff for which the channel was designed. The free board is 15 cm. Had the channel been triangular with the same side slope, what would have been the ridge height to discharge the same discharge? Assume n = 0·04. [P1/3(c) | 10M]
2021	• Differentiate between continuous contour trench and staggered contour trench. [P1/1(a) | 8M] • Discuss in brief about contour strip cropping, field strip cropping and buffer strip cropping used for conserving soil and water in a cultivated field. [P1/2(a) | 10M] • Calculate the spacing between the shelter-belt having a height of 15 m. The actual wind velocity at 15 m height is 18 kmph and threshold wind velocity at 15 m height is 9 kmph. The angle of deviation of prevailing wind direction perpendicular to the wind break is 10 degrees. [P1/2(b·i) | 10M]
2019	• Explain different types of engineering measures of soil erosion control. Mention the design criteria of contour bund. [P1/1(b) | 8M] • Design a parabolic-shaped waterway to carry a flow of 3 m^3/sec down a slope of 4 percent. An excellent stand of dub grass is to be maintained in the waterway. Assume the necessary data required for calculation and draw a parabolic cross-section. The maximum flow velocity allowed is 2·5 m/sec. [P1/1(e) | 8M] • Calculate the height of contour bund to be constructed on a land slope of 5 percent. Assume the following: (i) Rainfall excess for 24 hours duration is 80 cm (ii) 15 m is horizontal interval (iii) Depth of water flow over the weir is 30 cm. [P1/2(d) | 10M] • Write about design factors and layout to install shelter-belt against wind erosion. [P1/3(a) | 10M] • Write short notes on: (i) Grassed waterway (ii) Nalla bunding (iii) Movement of soil particles in wind erosion (iv) Vegetative measures for soil erosion control (v) Rational method for estimating runoff. [P1/4(b) | 10M]
2018	• What do you understand by biological or vegetative measures in a watershed? Describe the measures. [P1/1(b) | 8M] • What is contour trench? Write about different types of contour trenches. Explain design procedure of contour trench systems. [P1/2(d) | 10M] • Describe the classification of bench terraces given by Rama Rao and Bali, with suitable sketches. [P1/4(a) | 10M]
2017	• Write the step-by-step procedure for planning and design of a graded bunding. [P1/3(a) | 10M] • Design a grassed waterway of parabolic shape to carry a flow of 2·6 m^3/s, down a slope of 3%. The waterway has a good stand of grass and velocity of 1·75 m/s can be allowed. Assume the value of Manning's roughness coefficient 'n' as 0·04. [P1/3(b) | 10M] • Write short notes on the following: (i) Universal Soil Loss Equation (ii) Catchment Area Treatment (iii) Agronomic Erosion Control Measures (iv) Functions and Planning of Terraces (v) Elements of Flood Routing. [P1/4(b) | 10M]

	• It is planned to construct bench terraces on a 20% hill slope. If the vertical interval is 2 m, determine: (i) Length per hectare (ii) Earthwork (iii) Area lost, both for vertical cut and batter slope of 1 : 1. (The cut should be equal to fill). [P1/4(c) | 10M]
2016	• What are the contour and graded bunds? How do they differ in design and functional aspects?. [P1/1(b) | 10M] • Calculate the cross-section of a contour bund used to store 24-hour excess rainfall of 10 cm. The annual rainfall is about 120 cm with a high intake rate and there is low coverage of crops over the land. The land slope is 4%. Use Cox's formula for VI of contour bund. [P1/1(d) | 10M] • Design the dimensions of a weir used to discharge excess runoff through a contour bund for the conditions given: Land slope = 1·5%, Top width of the bund = 45 cm, Height of the bund = 60 cm, Height of crest above GL = 30 cm, Side slope of the bund = 2 : 1, VI = 1 m, Length of the bund = 400 m, Intensity of rainfall for the return period and time of concentration = 12 cm/hr. During the peak rainfall constant infiltration rate = 2·5 cm/hr. No water is stored behind the bund before the peak rainfall occurs. Determine the volume of water stored behind the bund before it starts flowing. [P1/2(c) | 20M] • Design a 150 m long inward sloping (5%) bench terrace for a sandy loam soil with an average slope of 15%. The entire width of the terrace acts as a channel which is provided with a uniform grade of 0·6%. The rainfall intensity for the return period and time of concentration is 20 cm/hr, runoff coefficient = 0·3, riser side slope = 1 : 1, shoulder bund height = 30 cm, bottom width = 75 cm, side slope = 1 : 1, Manning's n = 0·04, VI = 1·06 m, area of the terrace = 0·09 ha. [P1/3(c) | 20M] • Design a parabolic shaped grassed waterway to carry a flow of 3 cu m/s down a slope of 4%. An excellent stand of dub grass is to be maintained in the waterway. Take Manning's n = 0·04. [P1/4(c) | 20M]

Flood control, watershed mgmt. & land development

2025	• What are the principles and objectives of watershed management? Discuss the criteria used for prioritizing watersheds. [P1/3(a) | 15M] • Discuss in brief about compartmental bunding, intra-plot water harvesting, ridge furrow planting and field bunding methods used for in-situ water harvesting and moisture conservation. Enlist the ex-situ methods of water harvesting. [P1/3(b) | 10M]
2024	• Discuss in brief about storage reservoirs and detention reservoirs methods adopted for control of floods. [P1/1(d) | 8M] • Differentiate between the approaches of 'WARASA – Jan Sahbhagita' and 'Hariyali', the watershed development programmes. [P1/2(a) | 10M] • Explain the criteria for land levelling design. [P1/3(a) | 10M]

	• What is the basic premise in the Muskingum method of flood routing? Describe a procedure for estimating the values of Muskingum coefficient K and x for a stream reach. [P1/4(c) | 15M]
2023	• Discuss about the widely used in-situ water conservation practices for non-arable land with their suitability and limitation. [P1/2(a) | 10M] • What do you understand by watershed prioritization? How can you prioritize the watershed for treatment from soil erosion and sediment yield point of view using remote sensing and GIS techniques? [P1/4(c) | 20M]
2022	• Describe guiding principles for watershed development projects as stipulated in the common guidelines. [P1/1(a) | 8M] • What are sand dunes? Describe the procedure for fixing the sand dunes. [P1/1(b) | 8M] • Explain how the following are determined in plane method of land levelling design: (i) Centroid of the field (ii) Slope of the plane of best fit (iii) Formation levels, cuts and fills. [P1/3(b) | 15M]
2021	• What are the different conservation measures to be followed for the treatment of watershed having maximum stream order III?. [P1/3(b) | 10M]
2020	• Discuss various methods of in-situ moisture conservation applicable for crop production under dryland areas. [P1/1(b) | 8M] • Briefly describe various methods of reducing surface wind velocities in wind erosion control. [P1/2(a) | 10M] • Describe importance of stream ordering in watershed study. [P1/3(a) | 10M]
2019	• Write about the methods used for computation of earthwork. Also, write in brief about different machineries/equipments used for land grading. [P1/4(a) | 10M]
2018	• What is integrated watershed management approach? Explain its different objectives. [P1/1(c) | 8M] • Define hydrological drought. Write its components and their possible effects. List the measures that can be adopted to lessen the effects of drought in a region. [P1/1(d) | 8M] • Define flood routing. Discuss the basic elements of flood routing. [P1/3(c) | 10M] • What are the factors affecting land grading? How is survey carried out for land grading? Discuss commonly used methods for calculation of earth work. [P1/4(b) | 10M] • What are the different types of soil movement due to wind erosion? Describe how the movements of the particles of various sizes take place in different types of movement. [P1/4(d) | 10M]
2017	• Discuss the issues and challenges related to watershed management. What is the role of peoples' participation in watershed development? [P1/1(a) | 8M] • Discuss land shaping concepts, purpose and applicability in a watershed. [P1/1(b) | 8M]

	• Explain in brief, different methods of calculating earth and soil volumes. [P1/1(c) | 8M] • Explain the procedure to conduct a topographical survey of a watershed by direct contour method. [P1/1(d) | 8M] • Define Water Harvesting. Write the components and sequential steps for runoff water harvesting systems in the dry regions of India with suitable sketches. Also write the limitations of water harvesting systems. [P1/2(c) | 10M]
2016	• What are the main objectives of watershed management programme? What survey is required to be conducted while planning for watershed development? [P1/2(b) | 10M] • Describe in brief the runoff inducing practices for increasing runoff for water harvesting. [P1/3(a) | 10M]

Aerial photography & Remote sensing

2025	• Discuss the classification of remote sensing based on platform, energy source, regions of electromagnetic spectrum and number of bands. [P1/4(a) | 15M] • Discuss the importance and requirement of ground truthing in remote sensing. Explain the various parameters of ground truthing used for remote sensing of land cover types. [P1/4(b) | 15M] • Write short notes on the following: (i) Remote sensing data products (ii) Digital elevation models (iii) Types of cameras for aerial photography (iv) Forest cover mapping using remote sensing (v) Application of remote sensing for crop water stress monitoring. [P1/4(c) | 10M]
2024	• Distinguish between absorption and scattering of remote sensing energy. [P1/1(e) | 8M] • What are geometric correction and radiometric correction in digital image processing? [P1/3(c) | 15M] • Discuss the application of remote sensing in land cover and land use mapping. [P1/4(a) | 10M] • What is the significance of principal component analysis in digital image processing? Also write down the advantages of digital image processing. [P1/4(b) | 15M]
2023	• Explain the process of 'restoration' and 'geometric correction' in digital image processing. [P1/1(d) | 8M] • (i) What is false colour composite? (ii) Define atmospheric windows in relation to remote sensing. [P1/1(e) | 8M] • What are the basic keys of image interpretation? Also enlist the sequences followed in the process of image interpretation. [P1/4(a) | 10M] • How is classification done in digital image processing? [P1/4(b) | 10M]
2022	• (i) What do you understand by the word LANDSAT in image processing? (ii) What are the seasonal influences on images? [P1/1(d) | 8M]

	• Remote sensing (image interpretation) has been used for archaeological investigations. Explain with example. [P1/1(e) | 8M] • What are the factors that influence interpretation of the remote sensing images? Discuss different elements of air photo interpretation. [P1/4(a) | 20M] • What are the differences between NASA satellite pictures and those of geostationary weather satellite? [P1/4(b) | 10M] • For a stereo pair of figures, Vertical Exaggeration (VE) results because the perceived vertical scale is larger than the horizontal scale. Find the approximate amount of exaggeration for a case of stereo pair of figures in which air base is found to be 2000 m, height of the camera above terrain is 4000 m, apparent stereoscopic viewing distance is 50 cm, eye base for average adult is 7 cm. Interpret your findings. [P1/4(c) | 10M]
2021	• Discuss the ordering of each element of photointerpretation with respect to degree of complexity. [P1/1(e) | 8M] • Describe the importance of spatial, spectral and temporal resolution. [P1/4(a) | 10M] • Discuss the digital image processing sequence with the help of a flowchart. [P1/4(b) | 15M]
2020	• Differentiate between the following: (i) Geostationary satellite and Polar sun-synchronous satellite (ii) Active remote sensing and Passive remote sensing. [P1/1(d) | 8M] • Define various satellite orbital characteristics. [P1/1(e) | 8M] • Explain spectral reflectance curve with the help of neat sketch for soil, water and vegetation. [P1/4(a) | 15M] • What are the methods of digital image processing? Discuss any one in detail. [P1/4(b) | 10M] • Discuss the interaction of Electromagnetic Radiation (EMR) with the atmosphere and the Earth's surface. [P1/4(c) | 15M]
2019	• Explain briefly the application of remote sensing in water resources studies. [P1/1(c) | 8M] • Explain the types of computer-assisted operations in digital image interpretation and analysis. [P1/2(c) | 10M]
2018	• Define remote sensing. What are the different stages in remote sensing data acquisition and processing? Diagram showing remote sensing system for resource management from source to end use may be given. [P1/1(e) | 8M]
2016	• Classify remote sensing based on type of data acquisition. Explain in brief the application of remote sensing in agriculture and forestry. [P1/4(a) | 10M]

GIS Application

2025	• Explain the application of GIS in the area of water resource development and management. [P1/1(e) | 8M]
2021	• (i) How does raster data format differ from vector data format in GIS? (ii) Differentiate between specular and diffusive reflectance. [P1/1(c) | 8M] • Discuss about the GIS data types. [P1/1(d) | 8M] • Discuss application of remote sensing and GIS in Forest Management. [P1/4(c) | 15M]
2018	• What is GIS? Name the applications of remote sensing and GIS in land and water management. Briefly discuss any three applications. [P1/2(a) | 10M]
2017	• Discuss the principles of GIS and remote sensing and their applications in watershed development and management. [P1/4(a) | 10M]

Rference resources

- ***Soil and Water Conservation Engineering*** by R. Suresh, Standard Publishers Distributors, New Delhi.
- ***Soil and Water Conservation Engineering*** by Glenn O. Schwab, D. D. Fangmeier and W. J. Elliot, John Wiley & Sons, New York.
- ***Principles of Agricultural Engineering, Vol. II*** by A. M. Michael and T. P. Ojha, Jain Brothers, New Delhi.
- ***Land and Water Management Engineering*** by V. V. N. Murty and Madan K. Jha, Kalyani Publishers, Ludhiana.
- ***Engineering Hydrology*** by K. Subramanya, McGraw Hill Education, New Delhi.
- ***Soil Conservation*** by Norman Hudson, Iowa State University Press / Batsford Academic.
- ***Textbook of Remote Sensing and Geographical Information Systems*** by M. Anji Reddy, BS Publications, Hyderabad.
- ***Remote Sensing and Image Interpretation*** by T. M. Lillesand, R. W. Kiefer and J. W. Chipman, John Wiley & Sons, New York.
- ***Fundamentals of Remote Sensing*** by George Joseph, Universities Press, Hyderabad.
- ***Concepts and Techniques of Geographic Information Systems*** by C. P. Lo and Albert K. W. Yeung, PHI Learning, New Delhi.
- *ICAR–IISWC, Dehradun bulletins; NRSC/ISRO Remote Sensing Applications and Bhuvan geoportal; Forest (Conservation) Act, 1980 bare Act.*
- *Many other National/Internet magazines, news cuttings, MoEF&CC, ICAR & NRSC websites for data, pictures, graphs and concept clarity.*

CHAPTER

1

SOIL EROSION - FUNDAMENTALS

Mechanics of erosion | Rainfall & runoff | Hydrograph analysis | USLE / RUSLE / MUSLE

SYLLABUS (Paper I | Soil & Water Conservation): Mechanics and types of erosion (water & wind), their causes; rainfall, runoff and sedimentation; rainfall erosivity & soil erodibility; wind erosion process. Foundational hydrology — precipitation analysis, runoff & peak-flow, hydrographs & unit hydrographs, and the USLE/MUSLE soil-loss models —

Chapter Outline

1. **Scope & Basics of Soil Erosion**
2. **Mechanics of Water Erosion**
3. **Forms / Types of Water Erosion**
4. **Gully & Ravine Development**
5. **Wind Erosion**
6. **Soil Erodibility & Rainfall Erosivity**
7. **Soil-Loss Models — USLE / RUSLE / MUSLE**
8. **Sediment — Delivery Ratio, Yield, Channel Erosion**
9. **Measurement of Soil Loss**
10. **Precipitation & Rainfall Analysis**
11. **Runoff & Peak-Flow Estimation**
12. **Hydrographs & Unit Hydrograph**
13. **Streamflow / Runoff Measurement**

1 SCOPE & BASICS OF SOIL EROSION

Soil and water conservation (SWC) is the planned use, development and protection of soil and water resources so as to obtain optimum, sustained production while preventing the degradation of these resources. Controlling soil erosion is its central concern. In India, of the **328 million ha** of geographical area, about **68 M-ha are critically degraded and 107 M-ha severely eroded**, and roughly **144.12 M-ha** are affected by water and wind erosion — of which ~69 M-ha is critical and needs immediate attention.

Soil erosion : the process of detachment, transportation and deposition of soil particles (sediment) from the land surface by the agents of erosion — chiefly water and wind, and locally gravity and ice. The word derives from the Latin erodere, 'to eat away'.

Erosion is thus a **three-phase process**: (i) *detachment* of particles from the soil mass, (ii) *transportation* by the erosive agent, and (iii) *deposition* when the transporting energy falls below that needed to carry the load. *Sediment* is the end-product. Finer particles (silt) are detached and carried more easily than coarse sand.

Geological vs accelerated erosion: Geological (normal) erosion is the slow, natural wearing of the land, broadly in balance with soil formation. Accelerated erosion is the rapid, man-induced loss (deforestation, overgrazing, faulty cultivation) that far outpaces soil formation — it is the real problem SWC addresses.

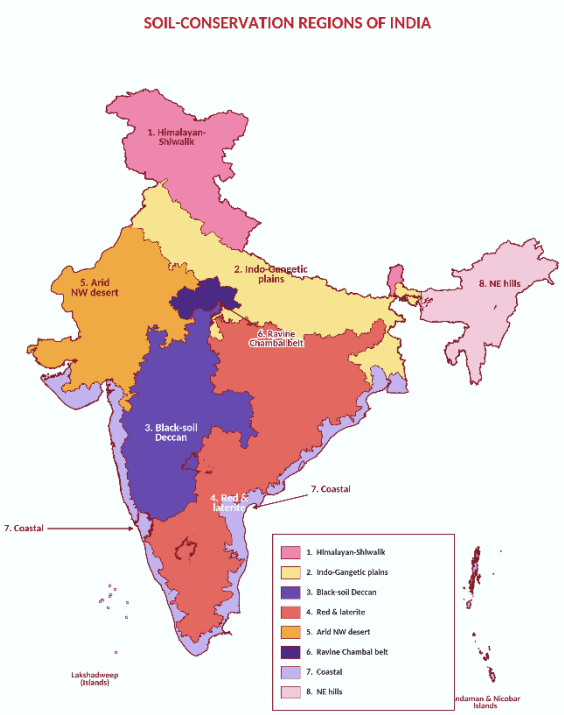
1.1 Causes of Soil Erosion in India

PREVIOUS YEAR QUESTIONS

- Main causes of soil erosion in India; agronomic practices for control.*** [IFoS 2016 | P1/1(a) | 10M]
- Why erosion is high in some regions and low in others. [AP·PSC 2018 | Q.1(c) | 6M]

The rate of erosion at a place is governed by the balance between erosivity (the eroding power of rain and wind) and erodibility (the susceptibility of the soil), modified by slope, vegetal cover and land use. The principal causes in India are:

- **Deforestation :** removal of natural vegetal cover exposes bare soil to raindrop impact and wind.
- **Overgrazing :** large livestock populations destroy ground cover and compact the surface.
- **Faulty cultivation :** up-and-down (vertical) ploughing, clean tillage, cultivation of steep slopes and fallowing.
- **Shifting (jhum) cultivation :** on steep North-Eastern hill slopes.
- **High-intensity monsoon rainfall :** large erosive energy delivered in a few months.
- **Topography & erodible soils :** steep slopes, loose alluvium and ravine soils.
- **Land disturbance :** mining, road-building and construction.



Erosion is high where intense rain, steep bare slopes and erodible soils coincide (Shiwaliks, ravines, NE hills) and low on flat, well-vegetated or cohesive-soil terrain. (*Agronomic / engineering control practices are treated in the Erosion-Control chapter.*)

© Hornbill Classes
+91 78802-71423 Hornbillclasses@gmail.com

1.2 Soil-Conservation Regions of India

PREVIOUS YEAR QUESTIONS

- Name the soil-conservation regions of India with salient problems.*** [IFoS 2019 | P1/1(a) | 8M]

Region	Salient soil-conservation problem
Northern Himalayan & Shiwalik	Landslides, steep-slope & terrace erosion, torrential hill streams, heavy run-off
Indo-Gangetic alluvial plains	Sheet erosion, water-logging, riverbank erosion; some wind erosion in the NW
Black-soil (Deccan / regur)	Sheet & gully erosion on cracking clays; deep gullies along streams
Red & laterite (peninsular)	Sheet & rill erosion, low fertility, surface sealing/crusting
Arid & semi-arid (NW desert)	Severe wind erosion, sand-dune movement, sparse cover
Ravine & gully (Chambal/Yamuna/Mahi)	Deep ravines & gully erosion of alluvial banks — the most spectacular erosion
Coastal region	Sheet erosion, coastal sand & wind action, salinity
North-eastern hills	Jhum (shifting-cultivation) erosion on steep, high-rainfall slopes

1.3 Impacts of Soil Erosion

PREVIOUS YEAR QUESTIONS

- Impacts of soil erosion on water quality. [IFoS 2025 | P1/1(b) | 8M]
- On-site and off-site impacts of soil erosion. [AP·PSC 2018 | Q.1(a) | 4M]
- How soil erosion affects agriculture. [OPSC·CSE 2019 | 20M]

On-site impacts (where erosion occurs)

- Loss of fertile topsoil and plant nutrients (N, P, K, organic matter) → falling fertility and yield.
- Reduced rooting depth, water-holding capacity and infiltration; structural deterioration and crusting.
- Rills, gullies and ravines that fragment and remove land from cultivation.
- Exposure of less-fertile subsoil and loss of soil organic carbon, reducing microbial activity and long-term soil health.
- Lower input-use efficiency and higher cultivation costs as more fertiliser, water and tillage are needed to sustain yields.
- Breakdown of soil structure and surface sealing that lowers seed germination and emergence, thinning the crop stand.
- Progressive land degradation and abandonment, lowering land value and threatening farm livelihoods and food security.

Off-site impacts (downstream / downwind)

- Sedimentation of reservoirs, tanks and canals — loss of storage capacity and project life.
- Aggradation of river beds → higher flood frequency; siltation of drainage and harbours.
- Dust storms and sand deposition (wind erosion).
- Eutrophication and pollution of water bodies as eroded sediment carries nutrients (N, P), pesticides and other agrochemicals.
- Damage to roads, bridges, culverts and other infrastructure, with increased dredging and maintenance costs.

- Reduced hydropower generation and shorter turbine life as silt-laden water abrades machinery and cuts reservoir head.
- Burial of fertile downstream farmland and standing crops under coarse, infertile sand and debris during floods.

Impact on water quality

- Increased turbidity & suspended-sediment load less light penetration, harm to aquatic life, higher treatment cost.
- Eutrophication — adsorbed N & P carried with sediment enrich water bodies → algal blooms and oxygen depletion.
- Transport of adsorbed pesticides, heavy metals and pathogens with eroded particles.
- Raised salinity and siltation reduce usefulness of water for irrigation and drinking.
- Smothering of fish spawning beds and benthic habitats by deposited sediment, reducing aquatic biodiversity and fishery yields.
- Higher water temperature as turbid, sediment-laden water absorbs more solar radiation, lowering dissolved-oxygen levels.
- Clogging of water-supply intakes, filters and irrigation channels, raising pumping, cleaning and maintenance costs.
- Acidification and contamination of water from sediment-bound mine spoil and acid-forming materials in degraded catchments.

MODEL Q Niche pointers : Corn mono-cropping for biofuel (AP 2018) raises erosion (low residue cover, intensive tillage, bare row inter-spaces) and depletes long-term productivity. Animal manure on the surface (AP 2018) reduces erosion by improving aggregation, infiltration and providing a protective cover that absorbs raindrop impact. ***

2 MECHANICS OF WATER EROSION

PREVIOUS YEAR QUESTIONS

- Factors affecting water erosion. [MH·PSC 2024 | Q.1(a) | 8M]
- Factors affecting soil erosion by water; if slope is increased 4×, relative increase in erosion. [IFoS 2018 | P1/3(b) | 10M]
- Raindrop characteristics important from the soil-erosion point of view. [OPSC·CSE 2018 | 10M]

Water erosion proceeds in the same three linked phases as erosion in general: **detachment**, **transportation** and **deposition**. Detachment is achieved mainly by *raindrop impact (splash)* and by the shearing drag of flowing water; transport is by splash and by overland/channel flow; deposition occurs where the transporting capacity of the flow falls below the sediment load.

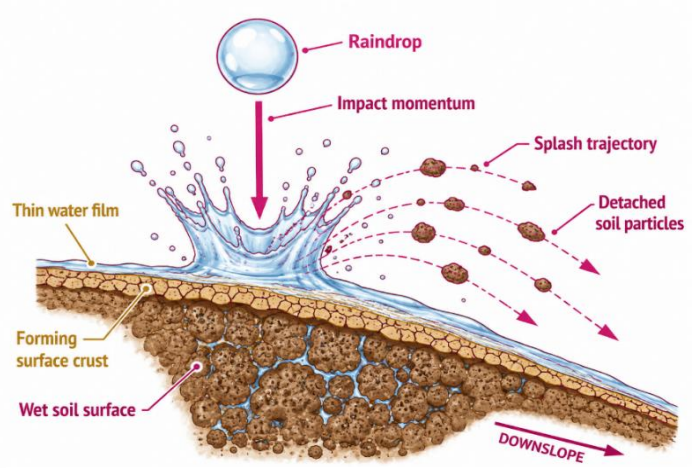
Limiting principle: Erosion at a point is limited either by the detachment capacity or by the transport capacity, whichever is smaller. Detachment needs energy; transport needs velocity. This is the conceptual basis of all soil-loss modelling.

2.1 Raindrop Characteristics that Govern Detachment

The kinetic energy of falling rain — not its mere amount — is the true eroding agent. The relevant raindrop properties are:

© Hornbill Classes
+91 78802-71423 Hornbillclasses@gmail.com

- **Drop size & size distribution :** larger drops (up to ~6 mm) carry more mass and energy; median drop size rises with rainfall intensity.
- **Terminal velocity :** the impact speed (up to ~9 m s^{-1}); governs the momentum delivered.
- **Kinetic energy (½mv^2) :** the actual detaching agent; KE increases with intensity, the basis of the **rainfall-erosivity index EI_{30}.**
- **Rainfall intensity & momentum :** high-intensity storms detach and transport far more soil.



Raindrop impact / splash mechanics

- **Drop shape & angle of impact :** affect the direction of splash, especially on slopes.

2.2 Factors Affecting Water Erosion

Factor group	How it controls erosion
Climate (rainfall)	Amount, intensity, duration, drop-size and frequency fix the erosivity; intense monsoon storms dominate in India.
Soil (erodibility)	Texture, organic matter, structure and permeability fix the soil's susceptibility (the K-factor).
Topography	Slope length and steepness — soil loss rises with both (see §6, LS-factor).
Vegetation / cover	Canopy intercepts rain, roots bind soil, residue absorbs impact and slows runoff — the C-factor.
Land use & management	Tillage direction, cropping system and conservation practices — the P-factor.

MODEL Q Slope : relation pointer (IFoS 2018): soil loss varies roughly as a power of slope steepness. Taking soil loss ∝ Sn with n ≈ 1.4 (RUSLE) or the older squared form, a 4× increase in slope gives a relative increase of 41.4 ≈ 7 times (≈ 16 times if the squared relation is used). The full LS derivation and worked example are in §6.***

3 FORMS / TYPES OF WATER EROSION

PREVIOUS YEAR QUESTIONS

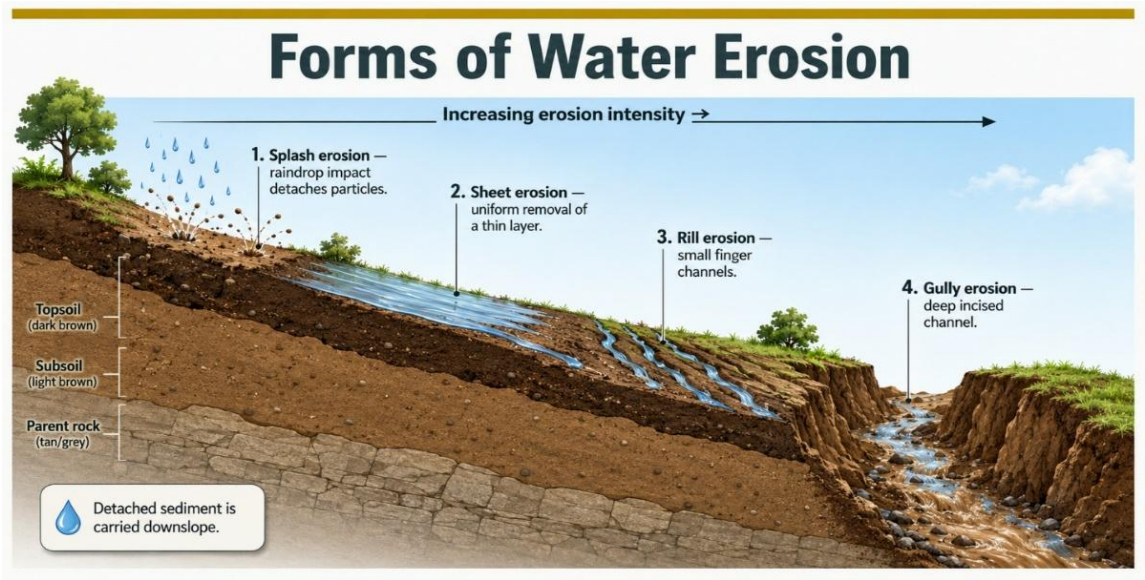
- Different types of erosion and their causes. *** [IFoS 2017 | P1/2(b) | 10M]
- What is soil erosion? Explain various types of water erosion. [UK·PSC 2025 | Q.1(I) | 10M]
- Different types of water erosion. [OPSC·CSE 2015 | 10M]
- Compare water vs wind erosion in terms of sediment transport. [AP·PSC 2018 | Q.1(b) | 6M]

Water erosion is classified by the way runoff concentrates, forming a natural progression of increasing severity:

1. **Splash (raindrop) erosion :** the first stage; raindrop impact detaches and throws soil particles, seals the surface and reduces infiltration.

2. **Sheet erosion :** near-uniform removal of a thin soil layer over the whole surface by shallow overland flow; insidious because it goes unnoticed until topsoil is lost.
3. **Rill erosion :** flow concentrates into many small finger-like channels (rills) that can still be smoothed out by tillage; the transition between sheet and gully erosion.
4. **Gully erosion :** rills enlarge into deep channels that cannot be crossed by farm machinery; the most advanced and conspicuous stage (see §4).
1. **Stream-bank / channel erosion :** scour and undercutting of banks and beds by flowing water in established channels.

⌖ *Source: Kumar et al., Ch.3, p.16–20 (PDF p.16–20); Mishra & Bal, Lesson 3 & 12, p.20–25, 84–90.*



3.1 Stream-bank vs Sheet/Rill — and Water vs Wind transport

In water erosion, sediment moves in *suspension, saltation and bed-load (rolling/sliding)* within the flow, sorted by particle size and flow velocity, and is delivered downstream to channels and reservoirs. In wind erosion (see 5) the analogous modes are *suspension, saltation and surface creep*, but the carrying fluid is air, so finer particles travel much farther and the deposition pattern is dust and dune rather than channel silt.

4 GULLY & RAVINE DEVELOPMENT

PREVIOUS YEAR QUESTIONS

- Different processes involved in the development of gullies. *** [IFoS 2024 | P1/1(b) | 8M]
- Stream-channel erosion (with sediment delivery ratio). [IFoS 2021 | P1/1(b) | 8M]

Gully - a deep, steep-sided channel cut by concentrated runoff that cannot be obliterated by normal tillage. When gullies coalesce into vast networks on deep alluvium (Chambal, Yamuna, Mahi) they form ravines — India's most spectacular erosion (~4 M-ha).

4.1 Stages / Processes of Gully Development

1. **Formation (channel erosion) :** concentrated overland flow scours a small channel as rill erosion deepens; flow energy exceeds soil resistance.
2. **Development (head-ward cutting) :** the gully head advances up-slope by waterfall/plunge-pool action; cross-section deepens and widens rapidly.

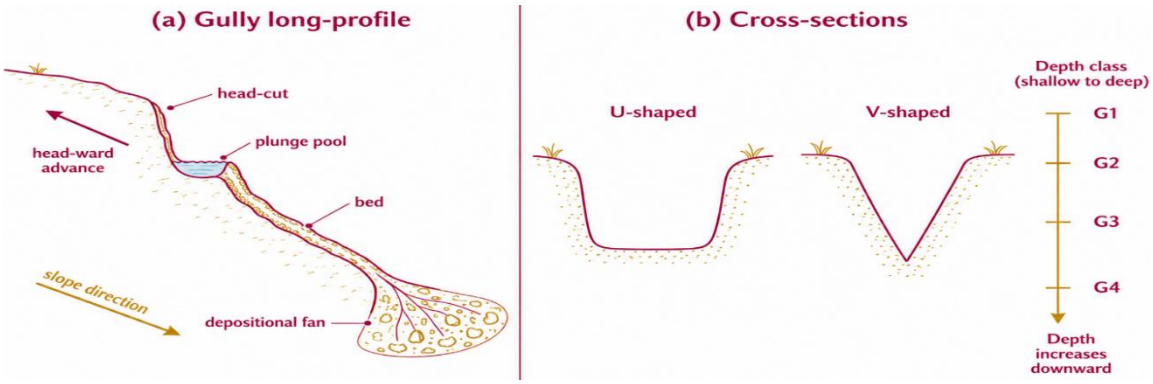
© Hornbill Classes
+91 78802-71423 Hornbillclasses@gmail.com

3. **Healing :** vegetation begins to establish on the gully floor and sides as gradient flattens; erosion slows.
4. **Stabilisation :** the gully reaches a stable gradient and cross-section; bed and banks attain a vegetal cover and erosion ceases. vegetation cover becomes complete and erosion effectively stops.

Source: Mishra & Bal, Lesson 7 (Gully Erosion), p.46–57 (PDF p.46–57); Kumar et al., Ch.4, p.21–33.

4.2 Classification of Gullies

Basis	Classes
Size / depth (continuous system)	Very small (G1, <1 m deep), small (G2, 1–3 m), medium/deep (G3, 3–9 m), very deep/large (G4, >9 m)
Shape of cross-section	U-shaped (uniform, easily eroded subsoil) vs V-shaped (resistant subsoil)
Activity	Active (advancing) vs inactive/stabilised (vegetated, stable gradient)



Gully cross-section & stages

5 WIND EROSION

PREVIOUS YEAR QUESTIONS

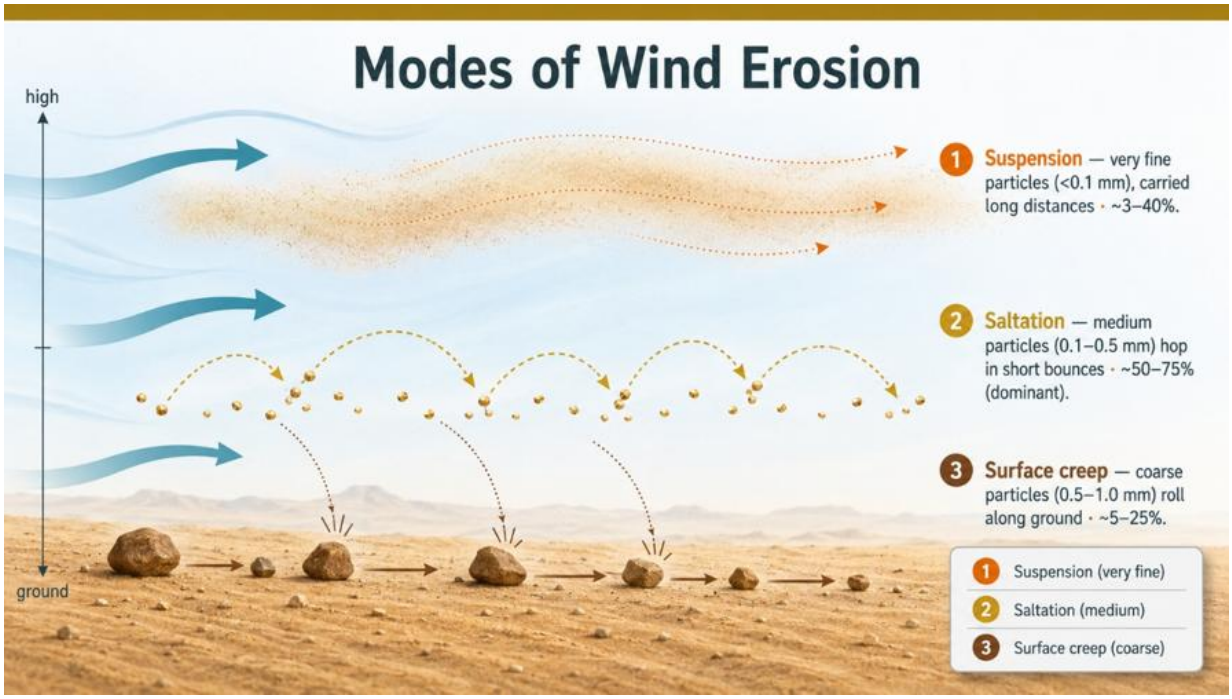
- Factors influencing soil erodibility by wind; impacts of types of water erosion. *** [IFoS 2025 | P1/2(b) | 15M]
- 'Erodibility index' and 'roughness factor' used for prediction of wind erosion. [IFoS 2023 | P1/3(a) | 10M]
- Phases of wind-erosion process; factors in estimation of soil loss by wind. [UK·PSC 2012 | Q.1(i) | 10M]

Wind erosion dominates the **arid and semi-arid NW (Rajasthan, Gujarat, Haryana)**, and its severity is *inversely related to rainfall* — the less the rain, the more the wind erosion. Like water erosion it involves detachment, transport and deposition, but air is the carrying fluid.

5.1 Phases / Modes of Soil Movement

Mode	Particle size	Description & share of moved soil
Suspension	< 0.1 mm	Fine dust lifted into the air, carried very high and over long distances; the most visible mode — about 3–40% of moved soil.
Saltation	0.1–0.5 mm	The major fraction — a series of bounces/jumps; travels ~4× longer in distance than in height; carries 50–75% of the moved soil.
Surface creep	0.5–2 mm	Large particles too heavy to lift are rolled along the surface by impacting saltating grains; 5–25% of the moved soil.

Over 93% of wind-borne soil moves at or within 1 m of the surface, and saltation is the engine that drives the other two modes.



5.2 Factors Affecting Wind Erosion (Erodibility by Wind)

- **Soil factors :** texture and particle size (loose, fine, dry sands most erodible), aggregate stability, non-erodible clods > 0.84 mm resist movement.
- **Soil moisture** : dry soil is far more erodible; moisture binds particles.
- **Surface roughness :** ridges/clods reduce wind velocity at the surface — the roughness factor.
- **Wind velocity & turbulence :** erosion increases sharply above the threshold velocity.
- **Climate :** wind velocity, turbulence and the temperature/evaporation regime (aridity).
- **Field length (unsheltered distance) :** longer bare fields along the wind direction lose more soil.
- **Vegetative cover :** standing residue and crops shelter the surface and trap moving soil.

5.3 Wind-Erosion Equation (WEQ) — Woodruff & Siddoway (1965)

The potential annual soil loss by wind, E, is expressed as a functional relationship of five groups of variables:

$$E = f(I, K', C, L', V)$$

Term	Meaning
I	Soil-erodibility index — potential erosion from a wide, bare, smooth, unsheltered field (depends on % non-erodible clods > 0.84 mm).
K'	Soil-ridge-roughness factor — the sheltering effect of surface ridges/clods.
C	Climatic factor — combines wind velocity and surface-soil moisture ($\propto V^3$ / (P-E index)^2).
L'	Unsheltered field-length along the prevailing wind direction.
V	Equivalent vegetative cover (quantity, kind and orientation of residue).

MODEL Q Direct answer to IFoS 2023: the 'erodibility index' (I) and the 'roughness factor' (K') are simply the first two terms of the WEQ — I is the field's inherent susceptibility (governed by non-erodible aggregate %), and K' is the reduction in that loss produced by surface ridge roughness.

© Hornbill Classes
+91 78802-71423 Hornbillclasses@gmail.com

6 SOIL ERODIBILITY & RAINFALL EROSIVITY

PREVIOUS YEAR QUESTIONS

- Methods of estimation of erosivity from rainfall data. *** [IFoS 2025 | P1/2(a) | 10M]
- Methods of estimation of rainfall-erosivity factor. [OPSC·CSE 2023 | 20M]
- Factors affecting soil erodibility. [AP·PSC 2018 | Q.1(d) | 4M]
- Calculate the soil-erodibility factor (K) for use in USLE. *** [OPSC·CSE 2020 | 12M]

Soil loss is the product of two opposing tendencies: the **erosivity** of the rain (its power to detach and transport) and the **erodibility** of the soil (its susceptibility). When erosivity exceeds the soil's resistance, erosion occurs.

6.1 Soil Erodibility (K-factor)

Soil erodibility is the inherent susceptibility (vulnerability) of a soil to detachment and transport by the agents of erosion. It is the soil's *own* contribution, independent of rainfall, slope or cover. The soil-loss rate per unit of rainfall erosivity from a standard unit plot (22.13 m long, 9% slope, continuous bare fallow, up-and-down tillage). It is the reciprocal of the soil's resistance to erosion; high for silts and fine sands, low for clays and well-aggregated soils.

Factors that raise erodibility

(i) **Texture** : silt and very fine sand are most erodible; clays resist detachment, sands resist transport.

(ii) **Organic matter** : binds aggregates, raises infiltration, lowers K.

(iii) **Soil structure & aggregate stability** : stable granular structure lowers K.

(iv) **Permeability** : rapid permeability lowers runoff and K.

Wischmeier nomograph equation (the working derivation)

$$100\,K = 2.1\times10^{-4} \mid M^{1.14}\,(12-a) + 3.25\,(b-2) + 2.5\,(c-3)$$

where M = (% silt + % very-fine sand) × (100 − % clay); a = % organic matter; b = soil-structure code (1–4); c = permeability code (1–6). K emerges in US units (t·ac·h per hundred·ac·ft·tonf·in); divide by 7.59 for SI (t·ha·h ha^{-1} MJ^{-1} mm^{-1}).

WORKED NUMERICAL — Soil-erodibility factor K (nomograph)

Problem (OPSC·CSE 2020; data illustrative) : Calculate the soil erodibility factor (K) for use in the Universal Soil Loss Equation, using the given information. (The original exam data table is not reproduced; representative values are used below.)

Given (illustrative soil)

Silt = 40%, very-fine sand = 25%, clay = 15%, organic matter a = 2.0%, structure code b = 2 (fine granular), permeability code c = 3 (moderate).

Step 1 : particle term M

$$M = (40+25)\,(100-15) = 65\times85 = 5525$$

Step 2 : substitute in the nomograph equation

$$100K = 2.1\times10^{-4}\,(5525)^{1.14}\,(12-2) + 3.25(2-2) + 2.5\,(3-3)$$

(5525)^1.14 ≈ 20 700; 100K = 2.1×10^{-4} × 20 700 × 10 + 0 + 0 = 43.5

$$K \approx 0.435 \text{ (US units)} = 0.435 / 7.59 \approx 0.057 \text{ t ha h ha}^{-1}\text{ MJ}^{-1}\text{ mm}^{-1} \text{ (SI)}$$

Result

K ≈ 0.44 (US) ≈ 0.057 (SI) — a moderately erodible silty soil. (Structure & permeability terms vanish here as b=2, c=3.)

6.2 Rainfall Erosivity (R-factor) and EI_{30}

Rainfall erosivity R - the potential of rainfall to cause erosion, measured as the number of erosion-index (EI_{30}) units. For a storm, the erosion index is the product of the storm's total kinetic energy (E) and its maximum 30-minute intensity (I_{30}).

Methods of estimating erosivity

1. **EI_{30} index (Wischmeier & Smith) : the standard method:** for each storm, erosivity = (total storm kinetic energy E) × (maximum 30-minute intensity I_{30}). The **R-factor = Σ EI_{30}** of all storms in a year, averaged over years. Requires recording-raingauge (intensity) data.
2. **Kinetic-energy computation :** E for each intensity increment from $e = 0.119 + 0.0873 \log_{10}(i)$ (MJ/ha·mm), summed over the storm; multiplied by I_{30}.
3. **KE > 25 index (Hudson)** : for tropical rains, only the energy of rainfall at intensity > 25 mm/h is counted (suited to high-intensity tropical storms).
4. **Fournier index / modified Fournier index** : uses monthly and annual rainfall (p^2/P) where intensity data are unavailable.
5. **Regional regression equations** : relate R to readily available annual/seasonal rainfall for Indian conditions.

Kinetic-energy–intensity relation

Erosivity rests on the fact that a storm's kinetic energy increases with its intensity. The unit-energy relations are:

$$KE = 916 + 331 \log_{10} I \quad \text{(US: ft·tonf per acre·inch, I in in h}^{-1}\text{)}$$
$$KE = 210.3 + 89 \log_{10} I \quad \text{(metric: tonne·m per ha·cm, I in cm h}^{-1}\text{)}$$

Storm and annual erosion index

$$EI_{30} = (\Sigma \text{ KE over storm increments}) \times I_{30}$$

Each storm's E is found by summing (unit-energy × rainfall depth) over its intensity increments, then multiplying by I_{30} (the greatest 30-min intensity). Summing storm EI_{30} over the year gives the annual R. Lines joining equal annual EI_{30} — **iso-erodent maps** — are drawn for ready use in the USLE.

WORKED NUMERICAL — Storm erosion index EI_{30}

P Problem (illustrative) : A storm occurs in three successive intensity blocks (data below) with a maximum 30-minute intensity of 6 cm/h. Compute the storm erosion index EI30. (Illustrative problem on the IFoS 2025 / OPSC 2023 theme — estimation of rainfall erosivity from rainfall data.)

Given a storm in three intensity blocks

Block 1: I = 2 cm h^{-1}, depth 1.0 cm. Block 2: I = 6 cm h^{-1}, depth 3.0 cm. Block 3: I = 4 cm h^{-1}, depth 1.0 cm. Maximum 30-min intensity I_{30} = 6 cm h^{-1}.

Step 1 : unit energy of each block (metric, $KE = 210.3 + 89 \log_{10} I$)

Block 1: $210.3 + 89 \log_{10}2 = 210.3 + 26.8 = 237.1$; Block 2: $210.3 + 89 \log_{10}6 = 210.3 + 69.2 = 279.5$; Block 3: $210.3 + 89 \log_{10}4 = 210.3 + 53.6 = 263.9$ (tonne·m/ha·cm).

Step 2 : energy of each block (unit energy × depth)

$$E = 237.1(1.0) + 279.5(3.0) + 263.9(1.0) = 1339.5 \text{ tonne·m ha}^{-1}$$

Step 3 : storm erosion index

$$EI_{30} = 1339.5 \times 6 = 8037 \text{ (tonne·m ha}^{-1}\text{) (cm h}^{-1}\text{)}$$

Result

Storm $EI_{30} \approx 8.0 \times 10^3$ metric units; the annual R is the sum of all storm EI_{30} in the year.

© Hornbill Classes
+91 78802-71423 Hornbillclasses@gmail.com

7 SOIL-LOSS MODELS — USLE / RUSLE / MUSLE

PREVIOUS YEAR QUESTIONS

- USLE — explain in detail the parameters in computing soil loss *** [IFoS 2019 | P1/2(a) | 10M]
- Differentiate USLE and MUSLE approaches; comment on utility ranges. *** [IFoS 2021 | P1/3(a) | 10M]
- USLE and how each factor is determined. [MH·PSC 2024 | Q.3(c) | 10M]
- Components of USLE; limitations in watershed management. [OPSC·CSE 2023 | 20M]
- How soil loss is estimated by USLE; what is its revised form? [OPSC·Forest 2019 | 20M]

7.1 Universal Soil Loss Equation (USLE)

Developed by **Wischmeier & Smith (USDA, 1965, revised 1978)** from over 10 000 plot-years of runoff-plot data, the USLE estimates the long-term *average annual* soil loss from sheet and rill erosion on arable land:



$$A = R \mid K \mid LS \mid C \mid P$$

Factor	Meaning & how it is determined
A	Computed soil loss per unit area per unit time (t ha^{-1} yr^{-1}).
R	Rainfall-erosivity factor = annual ΣEI_{30} (from iso-erodent maps) — §6.2.
K	Soil-erodibility factor (nomograph / unit-plot) — §6.1.
L	Slope-length factor = ratio of soil loss from the field length to that from a 22.13 m plot.
S	Slope-steepness factor = ratio of soil loss at field slope to that at the standard 9% slope.
C	Cover-management factor = ratio of loss under given cover to that from continuous bare fallow (≤1).
P	Support-practice factor = ratio of loss with a practice (contouring, strip-cropping, terracing) to that with up-and-down tillage (≤1).

Topographic factor LS — the slope derivation (IFoS 2018, 2025)

Slope length and slope loss combine in the LS factor. Wischmeier & Smith (metric) give:

$$LS = (\lambda / 22.13)^{m} \mid (65.41 \sin^2\theta + 4.56 \sin\theta + 0.065)$$

where λ = field slope length (m), θ = slope angle, and m = 0.5 for slopes ≥5%, 0.4 for 3–5%, 0.3 for 1–3% and 0.2 for <1%. Since $L \propto \lambda^{m}$ and the steepness term rises with $\sin^2\theta$, soil loss climbs steeply with both length and gradient.

WORKED NUMERICAL — Effect of slope steepness (IFoS 2018 — slope ×4)

P Question (IFoS 2018)

What are the factors which affect soil erosion by water? Discuss. If the degree of slope is increased 4 times, what will be the relative increase in erosion caused by water? (The factors are covered in §2; the slope part is worked here.)

Using the steepness term $S \propto \sin^2\theta$ (small-angle: $\sin\theta \approx \tan\theta \approx$ slope)

$$S \propto (\text{slope})^2 \Rightarrow S_2/S_1 = (4)^2 = 16$$

Using the RUSLE empirical exponent $S \propto (\text{slope})^{1.4}$

$$S_2/S_1 = 4^{1.4} \approx 7$$

Answer

Erosion increases about 16-fold on the classical squared relation, or ~7-fold on the RUSLE exponent — i.e. roughly an order of magnitude. State the assumption you use.

WORKED NUMERICAL — Average annual soil loss by USLE

Problem (illustrative) : *Using the Universal Soil Loss Equation, estimate the average annual soil loss from a maize field for which the rainfall-erosivity (R), soil-erodibility (K), slope length, slope steepness, cover-management (C) and support-practice (P) factors are given below.*

Given

R = 600 (MJ mm ha^{-1} h^{-1} yr^{-1}), K = 0.30, slope length λ = 100 m, slope = 9% (so the steepness ratio = 1), C = 0.25 (maize), P = 0.6 (contouring).

Step 1 : LS factor (λ=100 m, m=0.5; 9% slope ⇒ steepness term ≈ 1.0)

$$L = (100/22.13)^{0.5} = (4.52)^{0.5} = 2.13;\ LS \approx 2.13 \times 1.0 = 2.13$$

Step 2 : apply USLE

$$A = R \cdot K \cdot LS \cdot C \cdot P = 600 \times 0.30 \times 2.13 \times 0.25 \times 0.6$$

$$A \approx 57.5 \text{ t ha}^{-1} \text{ yr}^{-1}$$

Result

≈ 57.5 t ha^{-1} yr^{-1} — far above the tolerable limit (~5–12 t ha^{-1} yr^{-1}), so a conservation practice (lower C or P) is needed.

7.2 RUSLE — the Revised USLE (full treatment)

RUSLE (Renard *et al.*, 1997) keeps the form A = R·K·LS·C·P but re-derives every factor on a stronger process basis:

Factor	RUSLE refinement vs USLE
R	Same EI_{30} basis, but with much denser iso-erodent data and an equivalent-R for flat/snow regions; sub-monthly distribution used.
K	Time-varying (seasonal) K reflecting freeze–thaw, antecedent moisture and consolidation, not a single annual value.
LS	Re-derived for rill vs inter rill erosion. McCool slope-length exponent m = β/(1+β), β = (sinθ/0.0896)/(3 sin$^{0.8}$θ + 0.56); and S = 10.8 sinθ + 0.03 (slope <9%) or S = 16.8 sinθ − 0.50 (slope ≥9%).
C	Replaced by a continuous sub-factor product SLR = PLU | CC | SC | SR | SM (prior-land-use, canopy-cover, surface-cover, surface-roughness, soil-moisture) weighted over the year.
P	Expanded for contouring, strip-cropping, terracing and sub-surface drainage with improved values.

MODEL Q USLE→RUSLE in one line: same five factors, but K becomes seasonal, LS uses the McCool rill/inter rill formulation, and C becomes a continuous sub-factor product instead of a crop-stage table — giving better accuracy on complex slopes and rotations.

© Hornbill Classes
+91 78802-71423 Hornbillclasses@gmail.com

7.3 MUSLE — the Modified USLE (Williams, 1975)

Williams (1975) modified the USLE by replacing the rainfall-energy factor R with a **runoff-energy factor**, because runoff (not rainfall alone) carries the sediment off a watershed:

$$Y = 11.8\,(Q \mid q_p)^{0.56} \mid K \mid LS \mid C \mid P$$

where Y = sediment yield from a single storm (tonnes), Q = storm runoff volume (m^3) and q_p = peak runoff rate ($m^3\ s^{-1}$). The factors K, LS, C, P keep their USLE meaning. Because the runoff term embodies the transport process, MUSLE predicts **sediment yield directly per storm** and needs *no separate sediment-delivery ratio*.

WORKED NUMERICAL — Sediment yield by MUSLE

Problem (illustrative) : Using the Modified Universal Soil Loss Equation (MUSLE), estimate the sediment yield from a single storm for a watershed whose storm runoff volume (Q), peak runoff rate (qp) and K, LS, C and P factors are given below.

Given (single storm)

Q = 30 000 m^3, q_p = 6 $m^3\ s^{-1}$, K = 0.30, LS = 2.13, C = 0.25, P = 0.60.

Step 1 : runoff-energy term

$$(Q \cdot q_p)^{0.56} = (30\,000 \times 6)^{0.56} = (180\,000)^{0.56} \approx 1064$$

Step 2 : apply MUSLE

$$Y = 11.8 \times 1064 \times 0.30 \times 2.13 \times 0.25 \times 0.60$$

$$Y \approx 1203 \text{ tonnes (sediment yield from this storm)}$$

Result

≈ 1.2×10^3 t for the event — a per-storm sediment yield, delivered to the outlet without any delivery-ratio adjustment.

7.4 USLE vs MUSLE — comparison & limitations (IFoS 2021 banker)

Aspect	USLE	MUSLE
Driving factor	Rainfall erosivity R (EI_{30})	Runoff-energy factor $11.8(Q \cdot q_p)^{0.56}$
Output	Average annual gross soil loss	Sediment yield per individual storm
Delivery ratio	Needed separately to get yield at outlet	Not needed — yield is direct
Time scale	Long-term average (annual)	Single storm event
Best for	Field/plot sheet & rill erosion	Small watershed sediment yield (≈2–40 ha)
Process basis	Detachment by rain	Detachment + transport by runoff

Limitations common to the family

- Applies to sheet and rill erosion only — gully, stream-bank and mass erosion are not predicted.
- USLE gives gross soil loss, not the sediment actually delivered downstream (needs a delivery ratio).
- Empirical, factor values are region-specific; Indian values must be used for Indian conditions.
- Does not model deposition within the field, nor single-storm variability (USLE).

8 SEDIMENT — DELIVERY RATIO, YIELD & CHANNEL EROSION

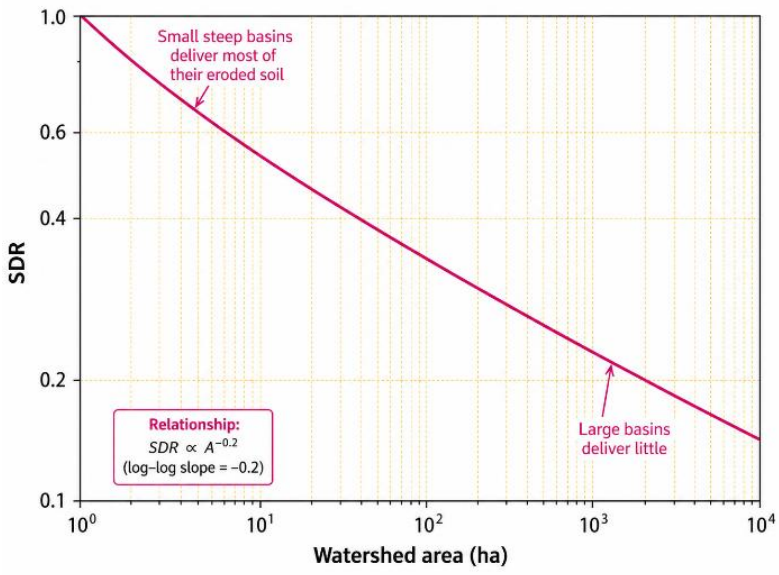
PREVIOUS YEAR QUESTIONS

- Sediment delivery ratio; stream-channel erosion [IFoS 2021 | P1/1(b) | 8M]
- Stream-bank erosion. [AP·PSC 2018 | Q.2(c) | 5M]

Sediment yield — the total sediment that actually leaves a watershed past a given point in a given time (t yr^{-1} or t ha^{-1} yr^{-1}). It is less than the gross erosion in the watershed, because much eroded soil is re-deposited on slopes, in channels and in flood-plains before reaching the outlet.

8.1 Sediment Delivery Ratio (SDR)

SDR is always ≤ 1 and **decreases as watershed area increases** (more opportunity for deposition en route) — empirically SDR ∝ A^(−0.2) for many basins. It also rises with steeper, well-connected channels and falls with flatter, vegetated, storage-rich catchments. SDR converts USLE gross soil loss into the sediment delivered downstream.



8.2 Stream-Bank & Channel Erosion

Once runoff is concentrated in defined channels, the flow itself erodes the **bed (degradation)** and **banks (lateral scour/undercutting)**. Bank erosion is driven by flow velocity and shear, bank height and saturation, freeze–thaw and the loss of riparian vegetation; it supplies a large part of the sediment in alluvial rivers and threatens land, bridges and embankments. It is the channel-stage counterpart of the upland sheet–rill–gully sequence.

9 MEASUREMENT OF SOIL LOSS

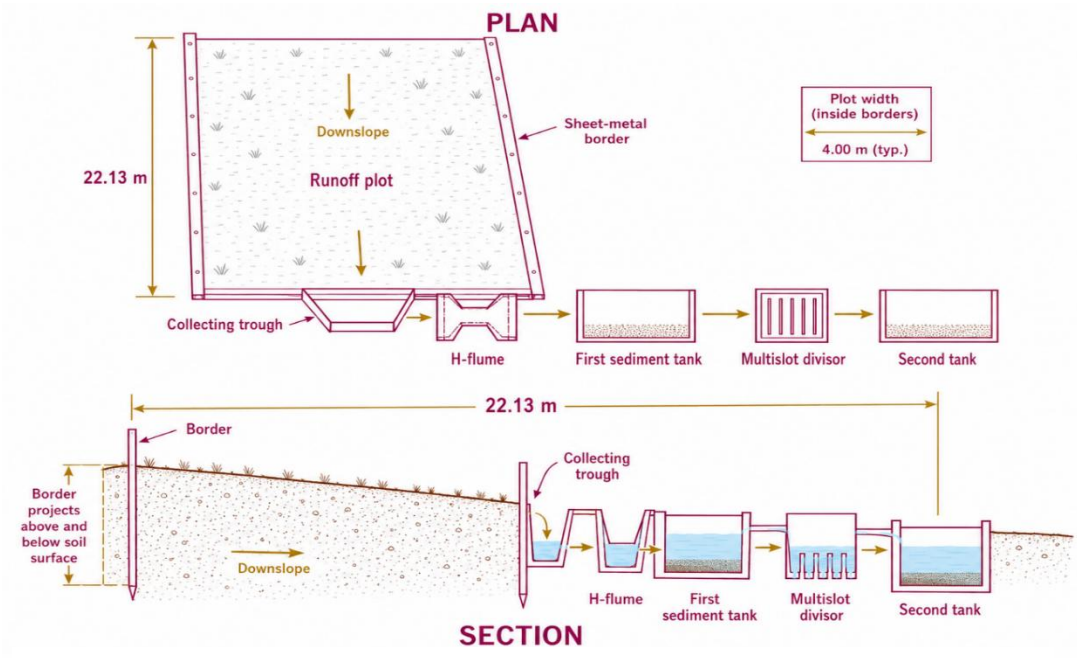
PREVIOUS YEAR QUESTIONS

- Different methods for measurement of soil losses from agricultural watersheds (use diagrams). *** [IFoS 2019 | P1/3(b) | 10M]

Soil loss is measured directly in the field by trapping the runoff and sediment from a defined area, or estimated from channel/reservoir surveys. The principal methods:

- **Runoff / erosion plots :** bounded plots (the standard USLE plot is 22.13 m long on 9% slope) with a border, a collection trough at the lower end leading to sediment tanks; runoff and sediment are weighed/sampled after each storm.
- **Multislot (Geib) divisors :** aliquot samplers that split large runoff volumes so only a known fraction is stored — used where tanks would otherwise overflow.
- **Small unit-source & large mixed watersheds :** gauged outlets with stage recorders and sediment samplers give watershed-scale sediment yield (links to §13).
- **Reservoir / tank sedimentation survey :** periodic capacity surveys give long-term average sediment yield of the catchment.
- **Profile / pin meters & tracers :** surface-lowering and radio-tracer methods for spatial patterns of loss.

© Hornbill Classes
+91 78802-71423 Hornbillclasses@gmail.com



Standard runoff-erosion plot

10 PRECIPITATION & RAINFALL ANALYSIS

PREVIOUS YEAR QUESTIONS

- Major types of precipitation storm. [IFoS 2025 | P1/1(a) | 8M]
- Salient characteristics of precipitation in India. [IFoS 2024 | P1/1(a) | 8M]
- Isohyetal method + advantages over arithmetic mean.*** [IFoS 2022 | P1/1(c) | 8M]
- Estimate missing rainfall at Station D (normal-ratio).*** [IFoS 2020 | P1/3(b) | 10M]
- Checking rainfall data of a station for consistency (double-mass). [IFoS 2018 | P1/2(c) | 10M]
- Depth-Area-Duration (DAD) curves + procedure. [IFoS 2017 | P1/2(a) | 10M]

10.1 Forms & Types of Precipitation

By the lifting mechanism, storms are **convective** (local heating, intense short showers/thunderstorms), **orographic** (air forced up mountains — the dominant Indian monsoon type, e.g. Western Ghats, NE hills), **cyclonic/frontal** (warm–cold air-mass interaction, depressions), and **monsoonal** (seasonal land–sea pressure reversal). Indian rainfall is *highly seasonal (≈75% in the SW monsoon, June–Sept), spatially variable (from <100 mm in the NW desert to >11 000 mm at Mawsynram), and high-intensity* — hence its great erosive power.

10.2 Mean Areal Rainfall over a Watershed

Point gauge values are converted to an average depth over the area by three methods of rising accuracy:

(a) Arithmetic-mean method

$$\bar{P} = (1/n)\,\Sigma\, P_i$$

Simple average of all gauges; adequate only for flat areas with uniformly distributed gauges and little spatial variation.

(b) Thiessen-polygon method (area-weighted)

$$\bar{P} = (\,\Sigma\, A_i\, P_i\,) \,/\, (\,\Sigma\, A_i\,)$$

Each gauge is weighted by the polygon area it represents (polygons formed by perpendicular bisectors of lines joining gauges). It accounts for non-uniform gauge spacing but assumes linear variation and fixed weights.

(c) Isohyetal method

$$\bar{P} = [\ \Sigma\ (\ (P_1+P_2)/2 \mid a\ )\ ]\ /\ A$$

Isohyets (equal-rainfall contours) are drawn; the area between successive isohyets is multiplied by their mean depth and summed. **Advantages over the arithmetic mean** (IFoS 2022): it uses the analyst's knowledge of orography and storm pattern, represents the true spatial distribution, and is the most accurate — whereas the arithmetic mean ignores spatial variation and gauge weighting.

WORKED NUMERICAL — Mean areal rainfall — Thiessen polygon

Problem (OPSC·Forest 2015) : Tabulated are the data derived from a drainage basin. Determine the average depth of rainfall using the Thiessen polygon method.

Given (4 gauges)

P = 26.9, 15.4, 28.2, 19.2 mm with Thiessen areas A = 108, 35, 18, 110 km² respectively.

Step 1 : $\Sigma A_i P_i$

$$= 26.9(108) + 15.4(35) + 28.2(18) + 19.2(110) = 2905.2 + 539 + 507.6 + 2112 = 6063.8$$

Step 2 : ΣA_i and weighted mean

$$\Sigma A = 271\ km^2;\ \bar{P} = 6063.8 / 271 = 22.4\ mm$$

Result

Area-weighted mean rainfall $\bar{P} \approx 22.4$ mm — note it differs from the plain arithmetic mean (22.4 vs 22.4 here; the gap widens when areas are very unequal).

10.3 Estimation of Missing Rainfall — Normal-Ratio Method

If the normal annual rainfalls of the gauges differ by more than 10%, the missing value P_x at a station is weighted by the ratio of normals:

$$P_x = (1/n)\ \Sigma\ (\ N_x / N_i\ )\ |\ P_i$$

where N_x is the normal annual rainfall at the missing station, N_i and P_i the normals and observed values at the n index stations.

WORKED NUMERICAL — Missing rainfall — normal-ratio (IFoS 2020)

Problem (IFoS 2020) : The normal annual rainfall at Stations A, B, C and D in the basin are 80.97, 67.59, 76.28 and 92.01 cm, respectively. In the year 1985, Station D was inoperative and Stations A, B and C recorded annual precipitation of 91.11, 72.33 and 79.89 cm, respectively. Estimate the rainfall at Station D in that year.

Given

Normals: N_A=80.97, N_B=67.59, N_C=76.28, N_D=92.01 cm. In 1985, D was inoperative; A, B, C recorded P_A=91.11, P_B=72.33, P_C=79.89 cm. Find P_D.

Normals differ >10% ⇒ use normal-ratio method (n = 3)

$$P_D = (N_D/3)\ [\ P_A/N_A + P_B/N_B + P_C/N_C\ ]$$

Step 1 : ratios

$$= (92.01/3)[\ 91.11/80.97 + 72.33/67.59 + 79.89/76.28\ ]$$

$$= 30.67\ [\ 1.1252 + 1.0701 + 1.0473\ ] = 30.67 \times 3.2426$$

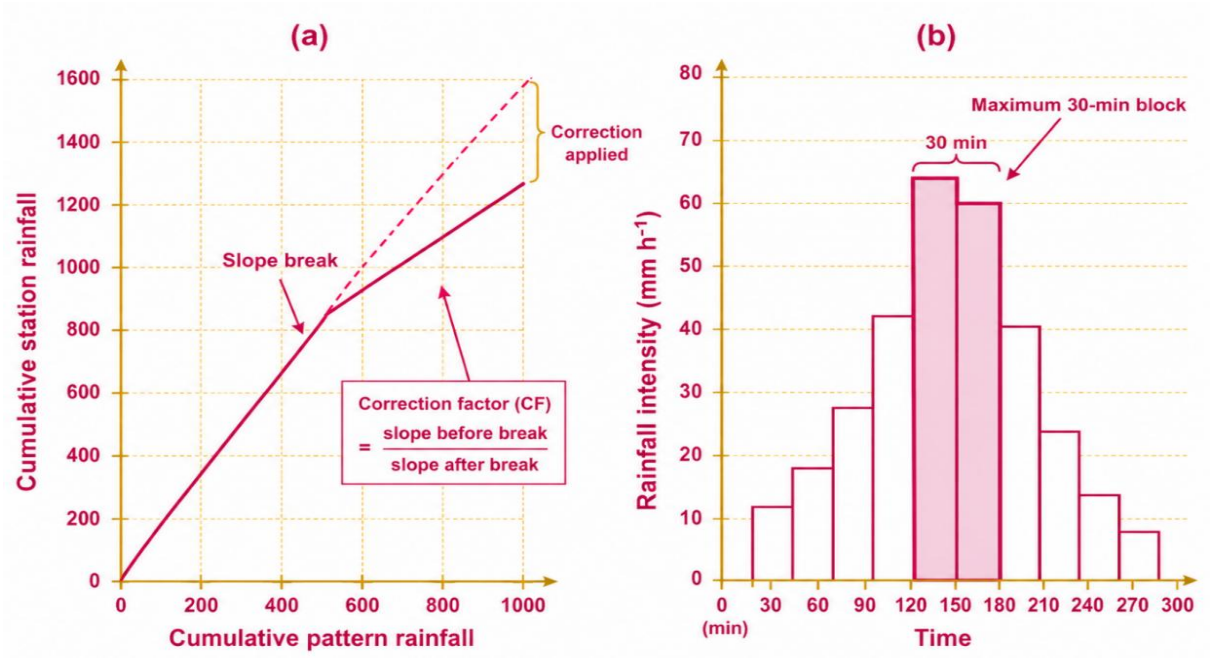
Result

$$P_D \approx 99.4\ cm$$

© Hornbill Classes
+91 78802-71423 Hornbillclasses@gmail.com

10.4 Consistency of Records (Double-Mass Curve) & DAD

A station's record may become **inconsistent** if its exposure changes (gauge shifted, trees grown). The **double-mass curve** plots the station's cumulative annual rainfall against the cumulative mean of surrounding stations; a *change in slope* marks the year of inconsistency, and the older record is corrected by the slope ratio. **Depth-Area-Duration (DAD)** curves give the maximum average depth over an area for a given duration built from isohyetal maps and storm mass curves — and are used in design-storm and flood studies.



Double-mass curve & hyetograph

11 RUNOFF & PEAK-FLOW ESTIMATION

PREVIOUS YEAR QUESTIONS

- Peak runoff, 10-yr, 250 ha, C=0.47, IDF given (numerical).*** [IFoS 2023 | P1/2(b) | 10M]
- Rational method; time of concentration (numerical). *** [IFoS 2018 | P1/2(b) | 10M]
- Rational formula; why 'rational'; limitations. *** [IFoS 2016 | P1/3(b) | 10M]
- Types of runoff; factors affecting runoff. [IFoS 2018 | P1/1(a) | 8M]
- SCS-CN method; factors influencing CN. [OPSC-CSE 2023 | 20M]

11.1 Runoff — Types & Factors

Runoff is the part of precipitation that flows over the land to a stream. **Surface runoff** reaches the channel quickly over the surface; **interflow (subsurface)** moves laterally through the soil; **base flow** is the delayed groundwater contribution. Runoff depends on *rainfall (amount, intensity, duration), catchment (size, shape, slope, orientation), soil & land use (infiltration, cover), and storage (lakes, dams)* — fan-shaped catchments give sharper peaks than fern-leaf ones.

11.2 Rational Method (peak flow)

For a uniform-intensity storm of duration ≥ the time of concentration, runoff at the outlet reaches a steady peak. The **rational formula** is:

$$Q_p = C \mid i \mid A \quad \text{(consistent units)} \;;\; Q_p = C\,i\,A / 360 \quad (Q \text{ in } m^3\,s^{-1},\ i \text{ in mm } h^{-1},\ A \text{ in ha})$$

where C = runoff coefficient (runoff/rainfall, 0–1), i = rainfall intensity for duration = t_c at the design frequency, A = catchment area. It is called '*rational*' because it rests on the rational premise that the peak occurs when the whole catchment contributes simultaneously (at t = t_c).

Time of concentration — Kirpich (1940)

$$t_c = 0.0195 \mid L^{0.77} \mid S^{-0.385} \quad (t_c \text{ in min}, L \text{ in m}, S = \text{bed slope})$$

Limitations of the rational formula

- Assumes constant uniform rainfall intensity over the whole catchment for the full t_c — valid only for small areas (typically < 50 km²).
- C is assumed constant, though it varies with storm depth and antecedent moisture.
- Gives only the peak, not the hydrograph shape or runoff volume.

WORKED NUMERICAL — Peak runoff by rational method (IFoS 2023)

Problem (IFoS 2023) : Determine the peak rate of runoff for a 10-year frequency from a watershed of 250 hectares, having a weighted value of runoff coefficient (C) as 0.47. The distance from the remotest point in the watershed to the outlet is 3000 m and the elevation difference between the highest and outlet points of the watershed is 25 m. The maximum intensity-duration-frequency relationship of the watershed is given by $i = (6.3117 \times T^{0.1523}) / (D + 0.50)^{0.945}$, where i = intensity in cm/h, T = return period in years and D = duration of rainfall in hours.

Given

A = 250 ha, 10-yr frequency, C = 0.47, L = 3000 m, elevation diff H = 25 m. IDF: $i = (6.3117\, T^{0.1523}) / (D + 0.50)^{0.945}$ cm h^{-1} (T yr, D h).

Step 1 : slope and time of concentration (Kirpich)

$$S = H/L = 25/3000 = 0.00833$$

$$t_c = 0.0195\,(3000)^{0.77}\,(0.00833)^{-0.385} = 0.0195 \times 552 \times 5.62 \approx 60.5 \text{ min} \approx 1.01 \text{ h}$$

Step 2 : design intensity at D = t_c, T = 10 yr

$$i = 6.3117(10)^{0.1523} / (1.01 + 0.50)^{0.945} = 6.3117 \times 1.420 / (1.51)^{0.945}$$

$$= 8.96 / 1.475 = 6.08 \text{ cm h}^{-1} = 60.8 \text{ mm h}^{-1}$$

Step 3 : rational formula (Q = C i A /360)

$$Q_p = 0.47 \times 60.8 \times 250 / 360 \approx 19.8 \text{ m}^3 \text{ s}^{-1}$$

Result

Design peak runoff ≈ 19.8 $m^3\ s^{-1}$ (≈ 20 $m^3\ s^{-1}$).

11.3 SCS Curve-Number (CN) Method

The US-SCS method estimates runoff depth Q from storm rainfall P using a single parameter, the **curve number CN**, which embodies soil type (hydrologic groups A–D), land use/cover and antecedent moisture (AMC I/II/III). It derives from the continuity premise $P = I_a + F + Q$ with the proportionality $F/S = Q/(P - I_a)$ and the standard initial abstraction $I_a = 0.2S$:

$$Q = (P - 0.2S)^2 / (P + 0.8S) \quad ; \quad S = (25400/CN) - 254 \quad (\text{mm})$$

For a watershed of several cover types, an area-weighted CN is used. AMC-II is the average condition; AMC-I (dry) and AMC-III (wet) are obtained from conversion tables.

WORKED NUMERICAL — Weighted CN & runoff (IFoS 2017 / 2020)

© Hornbill Classes
+91 78802-71423 Hornbillclasses@gmail.com

Problem (IFoS 2017) : Describe briefly the SCS-CN method of runoff estimation. A watershed has 100 ha area. The watershed has 20 ha pasture in silty clay soil of 2% slope (CN = 65), 30 ha of pasture on silty loam soil of 0.5% slope (CN = 70) and remaining 50 ha of wheat crop on loam soil of 1% slope (CN = 85). Estimate the weighted curve number for the watershed. (The direct runoff for a 120 mm storm is also worked below as an extension.)

Given (weighted CN, IFoS 2017)

100 ha = 20 ha (CN 65) + 30 ha (CN 70) + 50 ha (CN 85), all AMC-II.

Step 1 : area-weighted CN

$$CN = [20(65) + 30(70) + 50(85)] / 100 = (1300 + 2100 + 4250)/100 = 76.5$$

Step 2 : potential retention S

$$S = 25400/76.5 - 254 = 332.0 - 254 = 78.0 \text{ mm}$$

Step 3 : runoff for, say, P = 120 mm

$$Q = (120 - 0.2\times78)^2 / (120 + 0.8\times78) = (104.4)^2 / (182.4) = 10\,899 / 182.4$$

$$Q \approx 59.8 \text{ mm}$$

Result

Weighted CN = 76.5; for a 120 mm storm the direct runoff depth ≈ 60 mm (≈ 50% of rainfall).

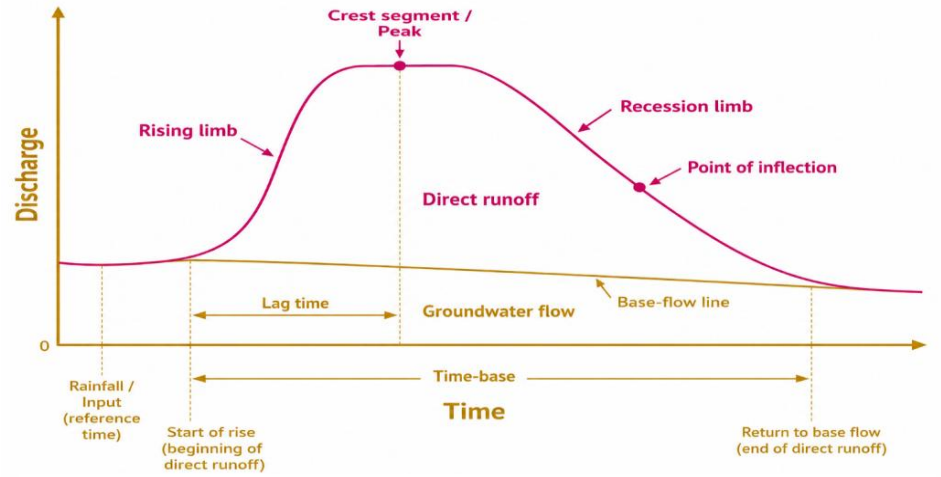
12 HYDROGRAPHS & UNIT HYDROGRAPH

PREVIOUS YEAR QUESTIONS

- Assumptions and steps in development of the unit hydrograph.*** [IFoS 2025 | P1/1(c) | 8M]
- UH; uses & limitations; S-curve method for other durations. *** [IFoS 2022 | P1/2(b) | 15M]
- Synthetic unit hydrograph & its derivation.*** [IFoS 2021 | P1/2(c) | 20M]
- Methods of base-flow separation from a runoff hydrograph. *** [IFoS 2020 | P1/3(c) | 20M]
- Drainage density; relation between drainage density and ruggedness number. [IFoS 2020 | P1/1(c) | 8M]

12.1 Hydrograph & its Components

Hydrograph — a plot of discharge against time at a stream section in response to a storm. A single-peaked hydrograph has a rising limb (concentration), a crest/peak, and a falling (recession) limb, sitting on the base flow; the area under the direct-runoff part equals the storm runoff volume.



Single-peaked hydrograph with components

12.2 Base-Flow Separation

To isolate direct runoff, base flow is separated by one of three standard methods:

1. **Straight-line method :** a horizontal line from the start of the rising limb to the point where the recession resumes.
2. **Fixed-base (N-day) method :** extend the pre-storm recession to under the peak, then join to the recession point N days after the peak, where N = 0.83 A^0.2 (A in km²).
3. **Variable-slope method :** project the master recession curve back to the inflection point and connect — best where groundwater response is significant.

12.3 Unit Hydrograph (UH) — Definition, Assumptions, Uses

Unit hydrograph — the direct-runoff hydrograph resulting from 1 unit (1 cm) of effective rainfall generated uniformly over the catchment at a uniform rate during a specified duration (the 'unit' duration).

Basic assumptions (Sherman, 1932)

- **Time invariance :** the UH for a catchment is constant (same storm always gives the same DRH shape).
- **Linearity / proportionality** : runoff ordinates are proportional to the effective rainfall depth.
- **Superposition :** DRHs from successive rain blocks add linearly.
- **Uniform distribution** : effective rainfall is uniform in space and time over the unit duration.

Uses & limitations

Uses : derive the flood hydrograph for any design storm, forecast floods, and transpose to ungauged basins (synthetic UH). Limitations: the linearity/time-invariance assumptions are only approximate; not valid for very large basins (>5000 km²), snowmelt, or highly non-uniform storms.

12.4 S-Curve & Unit Hydrographs of Different Durations

To change a UH from one duration to another, the **S-curve** (S-hydrograph) is used — the runoff hydrograph of a continuous effective rainfall of 1 cm per unit duration applied indefinitely. Two S-curves, one lagged by the desired new duration t', are subtracted and scaled:

$$UH(t') = (t / t') \mid [S(t) - S(t - t')]$$

WORKED NUMERICAL — 4-h UH from a 2-h UH via the S-curve (IFoS 2018)

Problem (IFoS 2018) : The ordinates of the 2-h unit hydrograph of a watershed are given for hours 0 to 22. Determine the ordinates of the S-curve hydrograph and, using the S-curve, determine the ordinates of the 4-h unit hydrograph of the watershed.

Method (steps)

1. Take the 2-h UH ordinates. 2. Build the S-curve by adding the 2-h UH to itself successively lagged by 2 h until it reaches equilibrium. 3. Lag the S-curve by the new duration t' = 4 h. 4. Subtract: S(t) − S(t−4). 5. Multiply by t/t' = 2/4 = 0.5 to get the 4-h UH ordinates.

Key relation

$$UH_4(t) = (2/4) \mid [S(t) - S(t-4)]$$

Result

The scaling factor 0.5 conserves the unit (1 cm) volume; the 4-h UH is lower and broader than the 2-h UH, as expected for a longer, gentler input.

12.5 Synthetic Unit Hydrograph & Drainage Density

© Hornbill Classes
+91 78802-71423 Hornbillclasses@gmail.com

For ungauged catchments, a **synthetic UH** is derived from basin characteristics. Snyder's method gives basin lag t_p = C_t (L·L_ca)^0.3, peak discharge Q_p = 2.78 C_p A / t_p, and the time base fixing peak, time-to-peak and width without observed data. Watershed geomorphology enters through **drainage density** and the **ruggedness number**:

$$D_d = \Sigma L / A \quad ; \quad \text{Ruggedness number } N = D_d \mid H \ (H = \text{basin relief})$$

Drainage density D_d (km km^{-2}) is the total channel length per unit area — high D_d means a finely dissected, quick-responding basin. The *ruggedness number* combines relief and drainage density (N = D_d·H, with H the relief), so a basin that is both steep and finely drained has a high N and a flashy, erosive hydrograph.

WORKED NUMERICAL — Drainage density & ruggedness number (IFoS 2020)

Problem (IFoS 2020) : Define drainage density and derive the relationship between drainage density and ruggedness number. (Illustrative numerical values are applied below to demonstrate the relationship.)

Given

Total channel length ΣL = 90 km, basin area A = 50 km², basin relief H = 0.4 km.

Step 1 : drainage density

$$D_d = \Sigma L/A = 90/50 = 1.8 \text{ km km}^{-2}$$

Step 2 : ruggedness number

$$N = D_d \mid H = 1.8 \times 0.4 = 0.72$$

Relation

N is the product of drainage density and relief; for fixed relief, N rises linearly with D_d — a finely drained, high-relief basin is hydrologically 'rugged' (flashy peaks, high erosion).

13 STREAMFLOW / RUNOFF MEASUREMENT

PREVIOUS YEAR QUESTIONS

Water-stage recorder; current meter as a flow-measuring device. **[IFoS 2016 | P1/4(b) | 10M]**

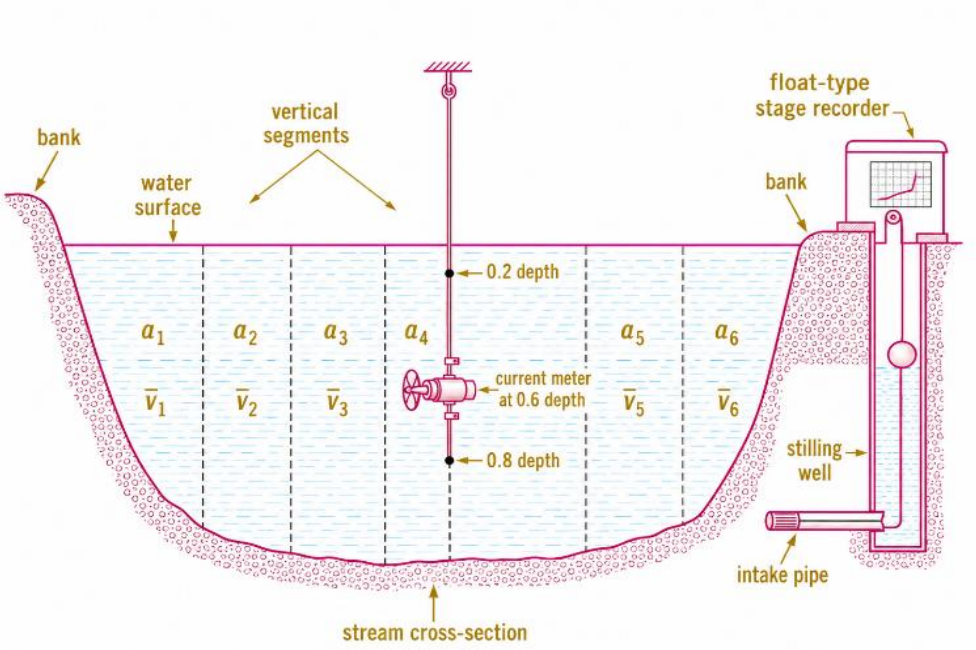
13.1 Stage (Water-Level) Measurement

Stage is the water-surface elevation above a datum. It is read on **staff gauges** (graduated scale) or recorded continuously by **automatic stage recorders**: the *float-type recorder* (a float in a stilling well drives a pen on a clock-driven chart or a digital encoder) and the *bubble-gauge* (measures the gas pressure needed to bubble out of a submerged orifice — preferred where a stilling well is impractical, and remotely transmittable).

13.2 Discharge by Current Meter

Discharge is the product of cross-sectional area and mean velocity. The **current meter** (cup-type/price or propeller-type) measures point velocity from the revolutions of its rotor (v = a + bN, N = revolutions per second). By the *velocity-area method*, the section is divided into verticals; mean velocity in each is taken at 0.6 depth (or the average of 0.2 and 0.8 depth), multiplied by the segment area, and the segment discharges are summed (mid-section method). A continuous **stage–discharge (rating) curve** then converts the recorded stage to discharge.

$$Q = \Sigma \left(a_i \mid \bar{v}_i \right) \quad ; \quad \text{point velocity } v = a + bN$$



Current-meter velocity-area gauging

© Hornbill Classes
+91 78802-71423 Hornbillclasses@gmail.com

CHAPTER

2

SOIL CONSERVATION MEASURES

Agronomic & vegetative measures | Land-capability classification | Contour & graded bunds | Contour trenches, stone walls & ditches | Bench terraces | Grassed waterways | Shelter belts — with full design derivations and worked numericals

OFFICIAL SYLLABUS — Chapter 2 scope

Biological and engineering measures for control of soil erosion — vegetative barriers, contour bunds, contour trenches, contour stone walls, contour ditches, terraces, outlets and grassed waterways. Wind-erosion control: shelter-belts and wind breaks. Agronomic and tillage practices for erosion control. Land-use capability classification.

Chapter Outline

1. Scope & Classification of Conservation Measures
2. Agronomic & Tillage Measures
3. Strip Cropping
4. Vegetative Measures & Wattling
5. Contour Bunds — Design
6. Graded Bunds — Design
7. Bench Terraces — Types, Design & Area Lost
8. Other Terraces & Contour Trenches
9. Contour Stone Walls & Conservation Ditches
10. Grassed Waterways — Design
11. Wind Breaks & Shelter Belts
12. Land-use Capability Classification
13. Allied Notes — Catchment-Area Treatment & Nalla Bunding
14. PYQ Coverage Matrix
15. Quick-Revision Formula Sheet

1. SCOPE & CLASSIFICATION OF CONSERVATION MEASURES

PREVIOUS YEAR QUESTIONS

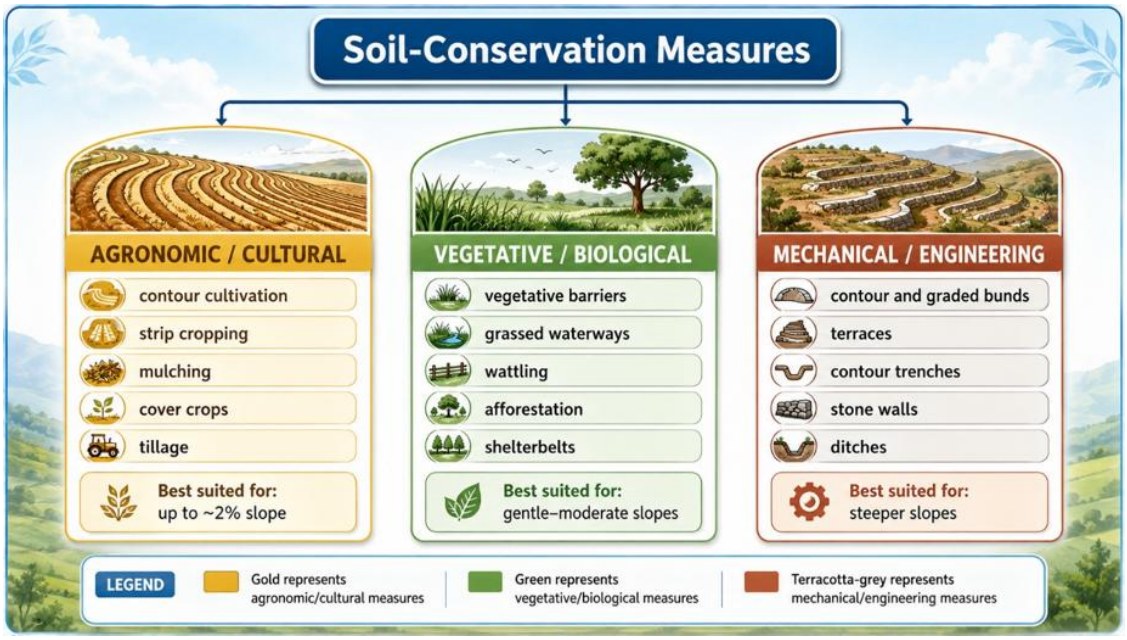
- Engineering measures for erosion control; design criteria of contour bund. [IFoS 2021 | P1/1(b) | 8M]
- Contour and graded bunds — design and functional differences. [IFoS 2016 | P1/1(b) | 10M]

Once the processes and agents of erosion are understood (Chapter 1), the next task is to control erosion and keep soil loss within the permissible (tolerable) limit. Soil-conservation measures do this on two complementary principles: (a) protect the soil surface and improve infiltration so that less runoff is generated in the first place, and (b) wherever runoff is unavoidable, reduce its velocity and lead it away safely. Every individual measure in this chapter is simply one of these two ideas applied to a particular land slope, rainfall regime and soil.

The measures fall into three broad families, almost always used in combination rather than alone:

Class	Principle & typical measures	Best suited to
Agronomic / cultural	Use the crop and the soil surface itself as cover — contour cultivation, strip cropping, mulching, cover crops, conservation tillage. Cheapest, first line of defence.	**Gentle slopes** up to ~2% (support role up to ~7%)
Vegetative / biological	Permanent living vegetation that binds soil and cuts velocity — vegetative barriers, grassed waterways, wattling, afforestation, shelter belts.	**Gentle-to-moderate slopes** where vegetation establishes
Mechanical / engineering	Earthen or masonry works that break slope length and impound or convey runoff contour & graded bunds, terraces, contour trenches, stone walls, ditches, waterways.	**Steeper slopes / higher runoff** where agronomic measures alone fail

The measure is selected by four governing variables that recur throughout this chapter: land slope, rainfall amount and intensity, soil depth and permeability, and intended land use. As a working rule, agronomic measures are used on slopes up to about 2% (and as a support up to ~7%), mechanical measures beyond that, and on long or steep slopes the two are combined — vegetation protecting the engineering works (bund tops, terrace risers, waterway linings) while the structures break the slope. The land-capability classification (§12) provides the formal framework for matching the right measure to each parcel of land.



© Hornbill Classes
+91 78802-71423 Hornbillclasses@gmail.com

2. AGRONOMIC & TILLAGE MEASURES

PREVIOUS YEAR QUESTIONS

- Vegetative management and tillage practices for control of wind erosion.*** [IFoS 2024 | P1/1(b) | 8M]
- Agronomic erosion-control measures; Catchment-Area Treatment. [IFoS 2017 | P1/4(b) | short note]

Agronomic (cultural) measures control erosion by managing the crop and the way the land is tilled, rather than by building anything. They work by keeping the surface covered, improving infiltration and reducing the erosive energy of falling rain and blowing wind. Because they cost little and are applied during ordinary farm operations, they are the first line of defence on cultivable land and the indispensable complement to every engineering structure. Their limitation is that, acting on the surface only, they lose effectiveness on steep slopes (above ~7%) and under very intense rain, where mechanical measures must take over.

PRINCIPAL PRACTICES

- **Contour cultivation :** all tillage, sowing and inter-culture carried out along the contour (across the slope); each furrow and crop row holds water, raises infiltration and checks runoff velocity. Effective up to about 7% slope.
- **Conservation / minimum tillage :** reduced tillage that retains crop residue and surface roughness, protecting the soil from raindrop impact and wind and raising infiltration.
- **Mulching :** a residue or straw cover that absorbs raindrop energy, suppresses evaporation and slows overland flow.
- **Cover & green-manure crops :** close-growing crops that bind the soil and add organic matter, lowering the cover (C) factor of the soil-loss equation.
- **Crop rotation & residue management :** alternating row crops with close-growing crops in time so that a protective canopy is maintained through the year.
- **Vegetative & tillage measures :** for wind erosion — keep the surface under a growing crop or standing stubble, plough across the wind, leave a cloddy or ridged surface, and grow cover strips to cut wind velocity and trap moving soil (IFoS 2024).

Catchment-Area Treatment (CAT) is the integrated application of these agronomic measures together with vegetative and engineering works over the whole catchment of a reservoir or project, to cut erosion and sediment yield and prolong the project's life; it is developed further in the Allied Notes (§13).

3. STRIP CROPPING

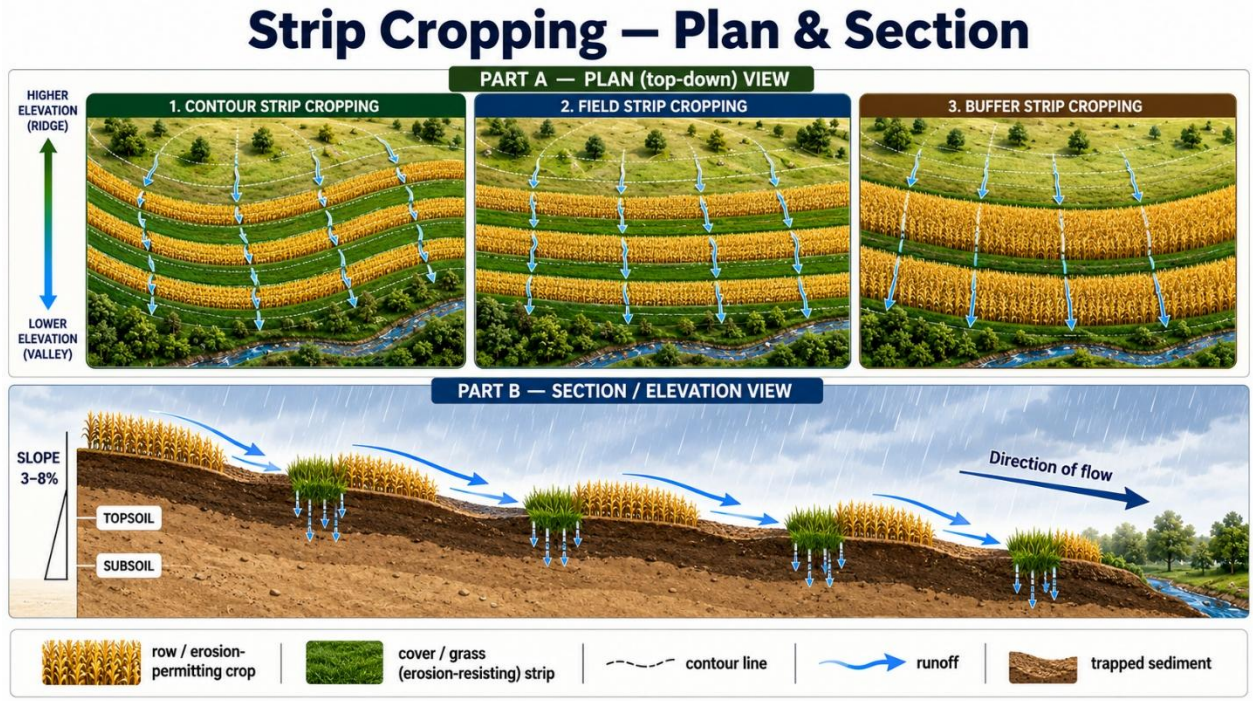
PREVIOUS YEAR QUESTIONS

- Contour, field and buffer strip cropping for conserving soil and water.*** [IFoS 2022 | P1/2(a) | 10M]
- Inter-cropping vs contour cropping vs strip cropping — design & effect. [AP·PSC 2018 | Q.3(a) | 10M]
- Contour / field / buffer strip cropping. [UK·PSC 2015 | Q.1(ii) | 10M]

Strip cropping is the practice of growing erosion-permitting (row) crops and erosion-resisting (close-growing) crops in alternate strips laid across the slope, so that every protective strip filters the runoff and traps the soil coming off the cultivated strip immediately above it. The slope is thus broken into many short lengths, and runoff is repeatedly slowed and cleaned as it moves downhill. It is most effective on uniform slopes of moderate gradient and is frequently combined with contour bunds or terraces. Three types are recognised:

Type	Description & use
Contour strip cropping	Strips laid exactly on the contour, alternating row and close-growing crops. The most effective form for erosion control; for uniform, moderate slopes.
Field strip cropping	Strips of uniform width laid across the general slope (not on exact contours) where the topography is too irregular for true contouring; easier to farm with machinery.
Buffer strip cropping	Permanent strips of grass or legume, of varying width, placed between the contour strips on the critical (steep or irregular) parts of a field; purely protective, not harvested as a cash crop.

These should be distinguished carefully, as the exam often asks. Inter-cropping grows two crops together in the same strip mainly for yield and risk benefit, with erosion control only incidental; plain contour cropping merely aligns a single crop's operations to the contour; strip cropping deliberately alternates protective and erosion-permitting strips across the slope with erosion control as the primary aim. The repeated resistant strips make strip cropping the most powerful of the three for conservation.



Source — Mishra & Bal, L4, p.26–30; Gully & Ravine Control Structures, L22, p.177–183.

4. VEGETATIVE MEASURES & WATTLING

PREVIOUS YEAR QUESTIONS

- Wattling — an erosion-control measure.*** [IFoS 2024 | P1/1(a) | 8M]
- Biological or vegetative measures in a watershed. *** [IFoS 2019 | P1/1(b) | 8M]
- When do you recommend biological measures for soil conservation? [AP·PSC 2012 | Q.2(J) | 5M]

Vegetative (biological) measures use living plants to protect the soil directly: the canopy intercepts rain and dissipates its energy, the roots bind the soil mass, and the stems slow runoff and trap the sediment it carries. They are the cheapest, most self-sustaining measures available and they improve soil health over time, so they are the first choice wherever slope and rainfall allow vegetation to establish. On steep slopes or under high runoff they are not abandoned but used in support of engineering structures as the grass lining of a waterway, the cover on a terrace riser, or the turf on a bund.

© Hornbill Classes
+91 78802-71423 Hornbillclasses@gmail.com

PRINCIPAL MEASURES

- **Vegetative barriers / live hedges :** close-planted rows of stiff, deep-rooted grass (e.g. vetiver/khus) or shrubs along the contour that slow runoff and trap sediment, forming a living, self-repairing barrier.
- **Grassed / vegetated cover :** permanent grass established on waterways, bund tops, terrace risers and gullied land to resist scour (designed as channels in §10).
- **Wattling :** a bio-engineering measure in which live cuttings or brushwood are bundled and staked in shallow trenches along the contour (or across gully beds) to form a 'wattle' fence; the stakes sprout, bind the soil and check downslope movement, giving permanent cover on unstable slopes and gully sides.



- **Afforestation / pasture establishment :** on Class VI–VIII land unsuited to cultivation, to provide permanent protective cover and stabilise degraded and steep ground.

When to recommend biological measures (AP·PSC 2012) : wherever the slope is gentle-to-moderate and rainfall and soil allow vegetation to establish; as the protective component of every watershed plan; and as the living cover on the engineering works themselves. On steep slopes or under high runoff they are used to support structures, not as the sole defence.

Source — Gully & Ravine Control Structures, L22, p.177–183; Mishra & Bal, L4, p.26–30.

5. CONTOUR BUNDS — DESIGN

PREVIOUS YEAR QUESTIONS

- Contour and graded bunds — how they differ in design and function.*** [IFoS 2016 | P1/1(b) | 10M]
- Engineering measures of erosion control; design criteria of contour bund. [IFoS 2021 | P1/1(b) | 8M]
- Principles of bund spacing; calculate bund height (L, V, W, S; rain 15 cm). *** [IFoS 2025 | P1/3(c) | 15M]
- Methods of bunds; design criteria & specification of contour bund. [OPSC·Forest 2023 | Q.1(c) | 10M]
- When do you recommend a contour vs a graded bund? [AP·PSC 2012 | Q.1(H) | 4M]

A bund is a small earthen embankment built across the slope to intercept runoff, reduce its velocity and impound or divert it, thereby breaking the slope into shorter lengths and trapping sediment. Built exactly on the contour it is a contour bund, which stores water for in-situ moisture; given a slight longitudinal grade it becomes a graded bund (§6), which safely leads excess water away. Bunding is the cheapest mechanical measure and the single biggest source of design numericals in this paper, so the geometry below must be mastered.

Basis	Contour bund	Graded bund
Alignment	Exactly on the contour (level)	On a slight grade, 0.2–0.4%
Function	Impounds & stores runoff for infiltration / in-situ moisture	Safely disposes of excess runoff to a protected outlet

Adoptability	Low rainfall (<600 mm), permeable soils, slope <6%	High rainfall / relatively impervious, low-infiltration soils
Channel & drainage	No graded channel; stores water behind the bund	Graded channel along the bund with a safe outlet/waterway
Main risk	Breaching if overtopped in heavy rain	Lower breach risk; depends on a stable outlet

When to recommend : choose a contour bund where conserving moisture is the priority — low rainfall and steep, permeable soils. Choose a graded bund where excess runoff must be removed high rainfall and/or clayey, low-infiltration soils on which impounded water would damage the crop.

5.1 Design elements & formulae

Designing a contour bund means fixing four things: the vertical interval (VI) and the horizontal interval (HI) that set the spacing; the cross-section that must store the design runoff; and a surplus weir for safe overflow. The spacing is fixed first.

VERTICAL INTERVAL — COX'S AND RAMSER'S FORMULAE

The vertical interval is the vertical drop between two successive bunds; the horizontal interval is the corresponding distance measured along the ground. The most widely used Indian relation is Cox's formula, with Ramser's as the older alternative:

Cox: VI = 0.3 (X·S/3 + Y) m Ramser: VI = 0.305 (S/3 + 2) m

where S = *land slope (%)*; X = *rainfall–infiltration index* and Y = *cropping/cover index*, both read from the standard ICAR table. The horizontal interval then follows from the slope, and the bund height from the water it must store:

Factor	Value & meaning
X — rainfall–infiltration index	≈ 0.8 for scanty rainfall (<625 mm) / low intake; ≈ 0.6 for moderate rainfall; ≈ 0.4 for heavy rainfall (>875 mm) / high-intake soils.
Y — cropping / cover index	1.0 for poor cover and below-average infiltration; 2.0 for good cover and average/above-average infiltration; 1.5 when one factor is favourable and the other is not.

HI = 100·VI / S (m)

d = √(2·Pe·VI)

H = d + free board

∑ DERIVATION : Water depth behind a contour bund (the d = √(2·Pe·VI) formula)

Set-up. Behind a level contour bund the impounded water surface is horizontal while the ground rises up-slope at slope S (%).

Let

d - be the water depth at the bund face and

Pe - the depth of design excess rainfall (runoff) to be stored over the contributing strip.

Geometry of the ponded wedge. Because the water surface is horizontal and the ground rises at S%, the water backs up a horizontal distance of

(d : slope) or equals to = 100d/S

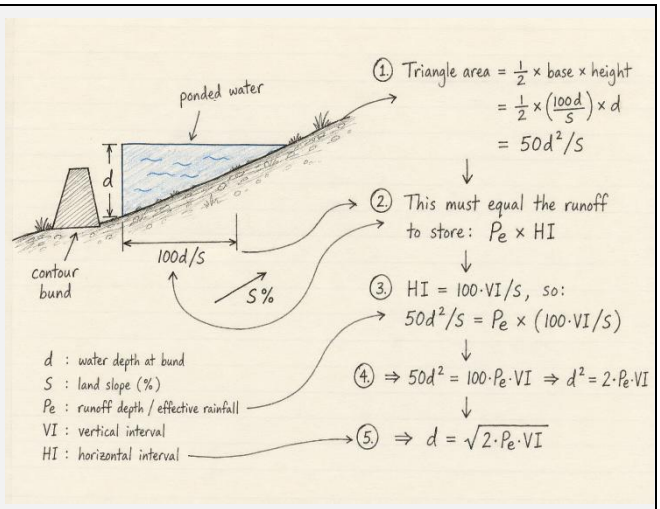
up the hill. The stored cross-section is therefore a triangle of base **100d/S** and

© Hornbill Classes
+91 78802-71423 Hornbillclasses@gmail.com

height d: Area stored per meter run = ½ | (100d/S) | $d = 50\,d^2 / S$

Equate storage to the runoff to be held. The runoff to be stored over the strip (per metre run) is the excess-rainfall depth times the horizontal interval, Pe | HI, and $HI = 100 \cdot VI/S$:

$$50\,d^2 / S = Pe \mid HI = Pe \mid (100 \cdot VI / S)$$
$$\Rightarrow \quad 50\,d^2 = 100 \mid Pe \mid VI$$
$$\Rightarrow d^2 = 2 \cdot Pe \cdot VI \quad \Rightarrow \quad d = \sqrt{(2 \cdot Pe \cdot VI)}$$

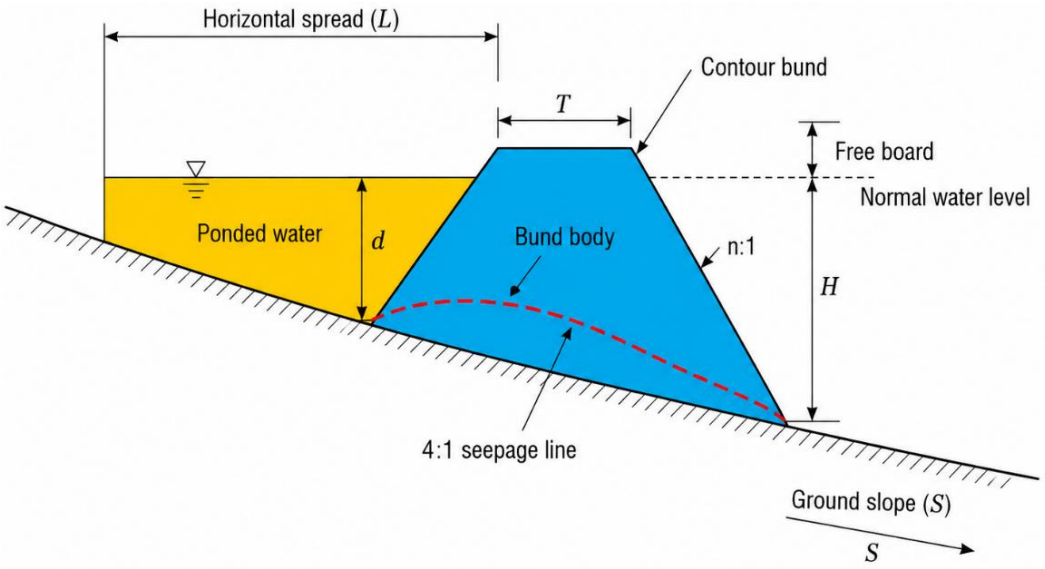


Note (correction) : The ponding spread is governed by the land slope S, not by the bund's internal seepage line; using a fixed seepage slope (e.g. 4:1) for the spread over-states the storage. The form above is the consistent one and is used in every worked problem below.

Bund height $H = d$ + *free board (free board ≈ 10–20% of H, or a fixed 15 cm).*

The body of the bund is then fixed by choosing a **top width** T *(≈ 0.3–0.6 m)* and a side slope n:1 (commonly 1.5:1 or 2:1), giving base width $B = T + 2nH$ and

the percentage of land lost to the bund = *base width : HI.*



5.2 Worked problems — contour bunds

⌘ Cross-section using Cox's formula

Full question. Calculate the cross-section of a contour bund used to store a 24-hour excess rainfall of 10 cm. The annual rainfall is about 120 cm with a high intake rate, and there is low crop cover. The land slope is 4%. Use Cox's formula for the VI of the contour bund. [IFoS 2016 | P1/1(d) | 10M]

Given:

- *Excess rainfall to store (24 h), Pe = 10 cm*
- *Annual rainfall ≈ 120 cm, with a high intake rate*
- *Crop cover = low*
- *Land slope, S = 4%*
- *Method to use: Cox's formula for VI*

Step 1 : VI by Cox's formula. High rainfall (120 cm) with high intake ⇒ X ≈ 0.8; low cover ⇒ Y ≈ 1.0 (ICAR table). S = 4%.

Cox: VI = 0.3 (X·S/3 + Y) m

$$VI = 0.3(0.8\times4/3 + 1.0) = 0.3(1.067 + 1.0) = 0.3\times2.067 = 0.62\ m.$$

Step 2 : Horizontal interval.

$$HI = 100\times0.62/4 = 15.5\ m.$$

Step 3 : Water depth to store.

$$d = \sqrt{(2\cdot Pe\cdot VI)}$$

$$Pe = 0.10\ m;\ d = \sqrt{(2\times0.10\times0.62)} = \sqrt{0.124} = 0.35\ m.$$

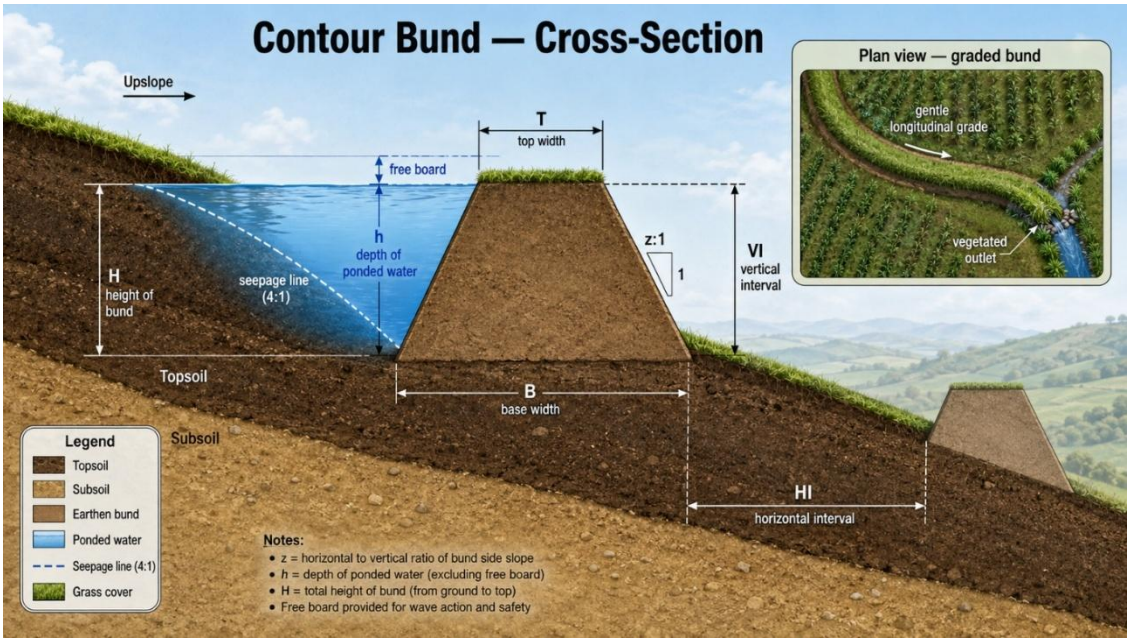
Step 4 : Bund height & cross-section (10% free board, top width 0.3 m, side slope 1.5:1).

$$H = d/0.9 \approx 0.39\ m;$$

$$base\ B = 0.3 + 2(1.5)\ (0.39) = 1.47\ m.$$

Answer. **VI ≈ 0.62 m, HI ≈ 15.5 m, water depth ≈ 0.35 m, bund height ≈ 0.39 m, base width ≈ 1.47 m.**

X and Y are read from the ICAR table for the stated rainfall and cover — state this assumption in the answer.



⌘ Design dimensions of a contour bund

Full question. Calculate the design dimensions of a contour bund in a medium-deep soil of average slope 3%. The maximum expected rainfall for a 10-year recurrence is 20 cm. The soil's infiltration capacity is such that 30% of the rain infiltrates. The horizontal interval between bunds is 60 m. Take the seepage-line slope as 4:1 and the bund side slope as 1.5:1. [IFoS 2022 | P1/2(c) | 10M]

Given:

- *Average slope, S = 3% (medium-deep soil)*
- *Maximum expected rainfall (10-yr recurrence) = 20 cm*
- *Infiltration = 30% of rainfall*
- *Horizontal interval, HI = 60 m*
- *Seepage-line slope = 4:1*
- *Bund side slope = 1.5:1*

© Hornbill Classes
+91 78802-71423 Hornbillclasses@gmail.com

Step 1 : Excess rainfall to store. 30% infiltrates ⇒

$$runoff = 70\% \text{ of } 20\ cm = 14\ cm \Rightarrow Pe = 0.14\ m.$$

Step 2 : VI from the given HI.

$$VI = HI \cdot S/100$$

$$VI = 60 \times 3/100 = 1.8\ m.$$

Step 3 : Water depth.

$$d = \sqrt{(2 \cdot Pe \cdot VI)}$$

$$d = \sqrt{(2 \times 0.14 \times 1.8)} = \sqrt{0.504} = 0.71\ m.$$

Step 4 : Bund height & cross-section (10% free board, top 0.3 m, side 1.5:1).

$$H = 0.71/0.9 \approx 0.79\ m;$$

$$base\ B = 0.3 + 2(1.5)(0.79) = 2.67\ m.$$

Answer. **VI = 1.8 m, water depth ≈ 0.71 m, bund height ≈ 0.79 m, base width ≈ 2.67 m; % area lost = 2.67/60 ≈ 4.4%.**

⌘ Bund design and % area lost (30-mark)

Full question. A contour bund is to be constructed on land of 2.5% slope. The vertical interval is 1.5 m and the area receives a maximum rainfall of 10 cm for a 10-year recurrence. One-fourth of the rainfall is lost as surface runoff. The bund side slope is 1.5:1; a free board of 10% of bund height is provided. Design the bund size and determine the percentage area lost to bunds. Take the seepage-line slope as 4:1. [OPSC·CSE 2018 | Q.7(a) | 30M]

Given:

- *Land slope, S = 2.5%*
- *Vertical interval, VI = 1.5 m*
- *Maximum rainfall (10-yr recurrence) = 10 cm*
- *Runoff = 1/4 of the rainfall*
- *Bund side slope = 1.5:1*
- *Free board = 10% of bund height*
- *Seepage-line slope = 4:1*

Step 1 : Excess rainfall (runoff).

$$One\text{-}fourth\ runs\ off \Rightarrow Pe = 0.25 \times 10\ cm = 2.5\ cm = 0.025\ m.$$

Step 2 : Horizontal interval.

$$HI = 100 \cdot VI/S$$

$$HI = 100 \times 1.5/2.5 = 60\ m.$$

Step 3 : Water depth.

$$d = \sqrt{(2 \cdot Pe \cdot VI)}$$

$$d = \sqrt{(2 \times 0.025 \times 1.5)} = \sqrt{0.075} = 0.274\ m.$$

Step 4 : Bund height (free board 10% of H).

$$H = d/(1-0.10) = 0.274/0.9 = 0.304\ m.$$

Step 5 : Cross-section & % area lost (top 0.3 m, side 1.5:1).

$$base = 0.3 + 2(1.5)(0.304) = 1.21\ m;$$

$$\%\ area\ lost = base/HI$$

$$HI = 1.21/60 = 2.0\%.$$

Answer. **HI = 60 m, water depth ≈ 0.27 m, bund height ≈ 0.30 m, base width ≈ 1.21 m, area lost ≈ 2.0%.**

⌘ Spacing & length of contour bund

Full question. Calculate the spacing and length of contour bund for a medium-rainfall area on 4 ha, if the land has a 5% slope. [OPSC·CSE 2020 | Q.6(b)(ii) | 12M]

Given:

- Area = 4 ha
- Land slope, S = 5%
- Rainfall category = medium (⇒ X ≈ 0.4, Y ≈ 1.0 from ICAR table)
- Method to use: Cox's formula for VI

Step 1 : VI by Cox's formula (medium rainfall ⇒ X ≈ 0.4, Y ≈ 1.0).

$$\text{Cox: } VI = 0.3\,(X \cdot S/3 + Y)\ m$$

$$VI = 0.3\,(0.4\times5/3 + 1.0) = 0.3(0.667 + 1.0) = 0.50\ m.$$

Step 2 : Spacing (horizontal interval).

$$HI = 100\times0.50/5 = 10\ m.$$

Step 3 : Total length of bund for 4 ha (= 40 000 m²).

$$Length = Area/HI = 40\,000/10 = 4\,000 \text{ m.}$$

Answer. **Spacing (HI) ≈ 10 m; total length of contour bund ≈ 4 000 m (4 km) for the 4-ha field.**

X and Y read from the ICAR table for medium rainfall.

⌘ Height of contour bund

Full question. Calculate the height of a contour bund on a land slope of 5%. Assume: (i) rainfall excess for 24 h = 80 cm; (ii) horizontal interval = 15 m; (iii) depth of water flow over the weir = 30 cm. [IFoS 2019 | P1/2(d) | 10M]

Given:

- *Land slope, S = 5%*
- *Rainfall excess for 24 h = 8 cm*
- *Horizontal interval, HI = 15 m*
- *Depth of water flow over the weir = 30 cm*

Step 1 : VI from the given HI.

$$VI = HI \cdot S/100 = 15\times5/100 = 0.75\ m.$$

Step 2 : Water depth to store the excess.

$$Pe = 0.08\ m$$

$$d = \sqrt{(2 \cdot Pe \cdot VI)}$$

$$d = \sqrt{(2\times0.08\times0.75)} = \sqrt{0.12} = 0.35\ m.$$

Step 3 : *Bund height = storage depth + weir-flow depth + free board*.

H = d + weir depth = 0.35 + 0.30 = 0.65 m (+ ~10% free board ≈ 0.72 m).

Answer. **Bund height ≈ 0.65–0.72 m.**

⌘ Bund-height expression & principles of spacing

© Hornbill Classes
+91 78802-71423 Hornbillclasses@gmail.com

Full question. Write the principles to be adopted while calculating the spacing of bunds (contour and graded). Also calculate the height of the bunds, given that the distance between bunds is L, the vertical interval is V, the width of water spread is W and the land slope is S%. Take the maximum rainfall standing behind the bund as 15 cm. [IFoS 2025 | P1/3(c) | 15M]

Given:

- ***Distance between bunds* = L**
- ***Vertical interval* = V**
- ***Width of water spread* = W**
- ***Land slope* = S%**
- ***Maximum rainfall standing behind the bund* = 15 cm**

Principles of bund spacing.

(1) Spacing is fixed by the vertical interval VI (Cox/Ramser) so that erosion between bunds stays within the permissible limit;

(2) $HI = 100 \cdot VI / S$;

(3) closer spacing on steeper slopes and on erodible, less-permeable soils;

(4) the bund must store or safely pass the design-frequency runoff;

(5) HI is also kept a convenient multiple of the implement width for farming.

Height expression. The water spreads a horizontal *width W* behind the bund and stands to a *depth d* at the bund face. For the maximum rainfall P = 15 cm = 0.15 m to be held over the strip of width W (per unit length), the stored cross-section ½·W·d must equal the rainfall volume P·W:

$\frac{1}{2} \cdot W \cdot d = P \cdot W \Rightarrow d = 2P = 2 \times 0.15 = 0.30\ m$

Height of bund $H = d + \text{free board} = 0.30 + 0.10H \Rightarrow H \approx 0.33\ m.$

Answer. d = 2P = 0.30 m; bund height H = d + free board ≈ 0.33 m (general form H = 2P/(1–f), f = free-board fraction). Spacing HI = 100·V/S.

5.3 Surplus weir (outlet) on a bund

PREVIOUS YEAR QUESTIONS

- Design a weir to discharge excess runoff through a contour bund. [IFoS 2016 | P1/2(c) | 20M]

Where a contour bund must pass surplus water, a surplus (waste) weir is provided. Its crest length is found from the weir formula, in which the design peak runoff Q (*rational method*) and a permissible head H over the crest give the required length:

$$Q = C_w \mid L \mid H^{(3/2)} \ (C_w \approx 1.7 \text{ SI}) \Rightarrow L = Q / (C_w \mid H^{(3/2)})$$

⌘ Surplus-weir design on a contour bund

Full question. Design the dimensions of a weir to discharge excess runoff through a contour bund: land slope 1.5%, top width of bund 45 cm, height of bund 60 cm, height of crest above ground level 30 cm, side slope 2:1, VI = 1 m, length of bund 400 m, rainfall intensity for the return period and time of concentration 12 cm/h, constant infiltration during peak 2.5 cm/h, no storage before the peak. Determine the volume stored behind the bund before it starts flowing. [IFoS 2016 | P1/2(c) | 20M]

Given:

- ***Land slope*, S = 1.5%**
- ***Top width of bund*, T = 45 cm**
- ***Height of bund*, H = 60 cm**

- *Height of crest above ground level = 30 cm*
- *Side slope = 2:1*
- *Vertical interval, VI = 1 m*
- *Length of bund = 400 m*
- *Rainfall intensity (for the return period and time of concentration) = 12 cm/h*
- *Constant infiltration during peak = 2.5 cm/h*
- *Assumption: no storage before the peak*

Step 1 : Peak runoff (rational method).

Excess intensity = 12 − 2.5 = 9.5 cm/h.

VI = HI·S/100

HI = 100×1/1.5 = 66.7 m;

catchment per bund = HI×length = 66.7×400 = 26 680 m² = 2.67 ha.

With C ≈ 1 (excess basis), i = 95 mm/h, A = 2.67 ha:

Q = C·i·A/360 = 1×95×2.67/360 ≈ 0.70 m³/s.

Step 2 : Storage before overflow (crest 30 cm above GL). Water stands to d = 0.30 m over a spread

Spread up the slope = 100d/S = 100×0.30/1.5 = 20 m.

Cross-section = ½×20×0.30 = 3.0 m²;

volume = 3.0×400 = 1 200 m³.

Step 3 : *Weir crest length (broad-crested, head H over crest).*

Head H = 0.60 − 0.30 = 0.30 m;

$L = Q / (C_w \mid H^{(3/2)})$

$L = Q/(1.7 \cdot H^{1.5}) = 0.70/(1.7 \times 0.164) \approx 2.5$ m.

(Note : For a broad-crested rectangular weir, the commonly used design coefficient (in SI/metric units, with Q in m³/s, L and H in metres) is Cw ≈ 1.7–1.84 $m^{0.5/s.}$ empirically calibrated for broad-crested weirs)

Answer. **Volume stored before overflow ≈ 1200 m³; required surplus-weir crest length ≈ 2.5 m (head 0.30 m). Bund base = 0.45 + 2(2)(0.60) = 2.85 m.**

6. GRADED BUNDS — DESIGN

PREVIOUS YEAR QUESTIONS

- Step-by-step procedure for planning and design of graded bunding.*** [IFoS 2017 | P1/3(a) | 10M]
- Graded bund: max runoff for a trapezoidal channel; equivalent triangular ridge height. ***
  [IFoS 2022 | P1/3(c) | 10M]

A graded bund carries a graded channel (longitudinal grade 0.2–0.4%) that collects runoff and conveys it at a non-erosive velocity to a protected outlet. It is used in higher-rainfall, less-permeable areas where storing water behind a level bund would be unsafe. The bund's earthen ridge is formed from the channel excavation; the channel itself is the design element and is sized by Manning's formula:

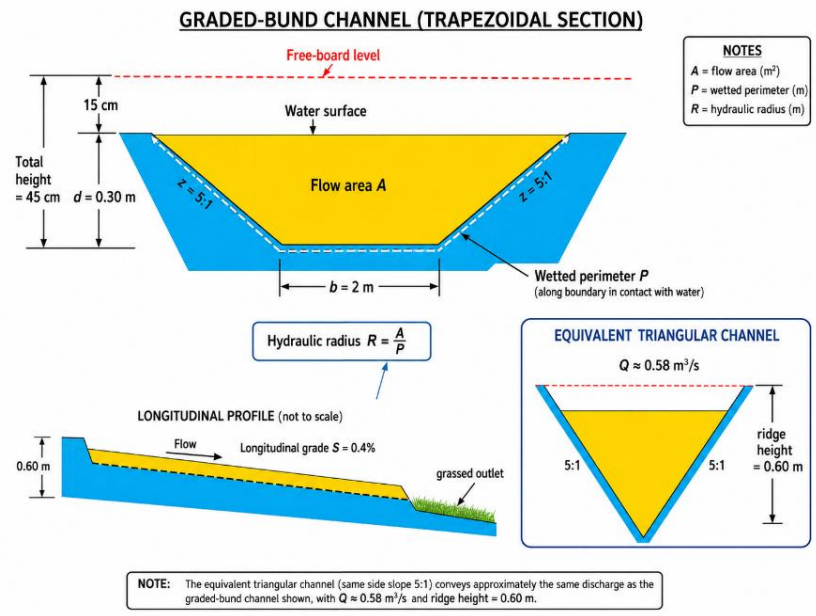
$$Q = AV$$

$$V = (1/n) \cdot R^{(2/3)} \cdot S^{(1/2)}$$

$Q = (1/n) \cdot A \cdot R^{(2/3)} \cdot S^{(1/2)}$ *Hydraulic radius* $R = A/P$ (free board ≈ 15 cm)

© Hornbill Classes
+91 78802-71423 Hornbillclasses@gmail.com

Permissible (non-erosive) velocity. The computed V must be checked against a safe range for the channel's soil or lining: too low a velocity causes silting, too high a velocity scours the channel. As a rule of thumb, loose erodible soils (sandy or sandy-loam) permit only low velocities (about 0.3 to 0.6 m/s); firmer clay-loam to stiff-clay soils allow higher velocities (about 0.9 to 1.5 m/s); a well-established grass lining can safely carry the highest velocities (up to about 1.5 to 1.8 m/s). If V exceeds the permissible limit, flatten the grade S, enlarge the section, or line the channel with grass or stone.



Channel shape, side slope and n. A trapezoidal section is standard, being easy to construct with a bund plough and stable in cross-section. The bottom width b and side slope z:1 are chosen from the soil's stability: loose, easily-erodible soils need flatter side slopes (z about 3:1 to 5:1, as used in the worked example below) while firm, stable soils can stand at z about 1.5:1 to 2:1. Manning's n is likewise matched to the channel surface: a freshly cut bare-earth channel is taken at n about 0.02 to 0.03, rising to n about 0.035 to 0.05 once weeds or grass establish (n = 0.04 in the worked example reflects a lightly vegetated channel).

PLANNING & DESIGN STEPS (IFOS 2017)

- fix the vertical interval VI (by Cox's formula, VI = 0.3(X·S/3 + Y) — the same spacing formula used for contour bunds) and horizontal interval HI = 100·VI/S for the bund layout.
- compute the design peak runoff Q (rational method) for the strip drained by the bund.
- choose the channel shape (usually trapezoidal), the grade (0.2–0.4%), the side slopes and Manning's n.
- size the channel by Manning's formula to carry Q at a safe (non-erosive) velocity; add free board (≈10–20% of the design depth d, or a fixed ~15 cm, whichever governs) to fix the ridge height.
- provide a stable, grassed outlet/waterway and align the bunds to lead into it.

⌘ Graded-bund channel capacity

Full question. A 200 m long graded bund is laid at a slope of 0.4%. The height of the graded bund, having a trapezoidal channel, is 45 cm; the channel bottom width is 2 m and the side slopes are 5:1 each. Determine the maximum runoff for which the channel was designed (free board 15 cm). Had the channel been triangular with the same side slope, what ridge height would discharge the same flow? Take n = 0.04. [IFoS 2022 | P1/3(c) | 10M]

Step 1 : Flow depth. $d = 0.45 - 0.15 = 0.30\ m$; $b = 2\ m$, $z = 5$, $S = 0.004$, $n = 0.04$.

Step 2 : Trapezoidal section.

$A = bd + zd^2 = 2(0.30) + 5(0.30)^2 = 0.60 + 0.45 = 1.05\ m^2$;

Wetted perimeter: $P = b + 2d\sqrt{(1+z^2)} = 2 + 2(0.30)\sqrt{26} = 5.06\ m$;

Hydraulic radius: $R = A/P = 0.208\ m.$

Step 3 : Manning's velocity & discharge.

$V = (1/n)\cdot R^{(2/3)}\cdot S^{(1/2)}$

$V = (1/0.04)\ (0.208)^{(2/3)}\ (0.004)^{(1/2)} = 25\times0.352\times0.0632 = 0.55\ m/s;$

$Q = A\cdot V = 1.05\times0.55 \approx 0.58\ m^3/s.$

Step 4 : Equivalent triangular channel (z = 5) for the same Q. Solving Q = 0.58 m^3/s with

A = zd^2, P = $2d\sqrt{(1+z^2)}$ gives flow depth d ≈ 0.45 m; ridge height = 0.45 + 0.15 = 0.60 m.

Answer. Design discharge ≈ 0.58 m^3/s; an equivalent triangular channel needs a ridge height ≈ 0.60 m.

7. BENCH TERRACES — TYPES, DESIGN & AREA LOST

PREVIOUS YEAR QUESTIONS

- Derive the % area lost for a bench terrace; batter 1:1 and ½:1.*** [IFoS 2023 | P1/2(c) | 20M]
- Classification of bench terraces by Rama Rao & Bali, with sketches. *** [IFoS 2018 | P1/4(a) | 10M]
- Objectives, types, limitations and precautions to avoid failure of terraces. [IFoS 2024 | P1/2(b) | 10M]
- Bench terraces on 20% slope; length/ha, earthwork, area lost. NUM [IFoS 2016 | P1/3(c) | 20M]
- Design a 150 m inward-sloping bench terrace (sandy loam, 15% slope). [IFoS 2016 | P1/3(c) | 20M]
- Bench terracing — objectives, types, suitability. [MH·PSC 2024 | Q.2(a) | 15M] | [HP·PSC 2021 | Q.1(b) | 10M]

A bench terrace is a series of level (or nearly level) strips benches running across the slope, separated by vertical or near-vertical risers. It converts a long, steep slope into a staircase of short level fields, reducing the effective slope length on each bench to nil and so eliminating the main driver of water erosion. Bench terracing is the most effective — and the most expensive — mechanical measure, suited to slopes of about 16–33% (and up to ~50% on stable soils).

OBJECTIVES, LIMITATIONS & PRECAUTIONS AGAINST FAILURE (IFOS 2024)

Objectives: reduce slope length and steepness to nil on the bench, retain moisture, control erosion and make steep land cultivable.

Broad types: (a) **Bench terraces** convert steep slope into a series of level/near-level steps; (b) **Broad-base/channel terraces** low, wide ridges-and-channels for gentler slopes (graded or level); (c) **Conservation/zing terraces.**

Limitations: very high earthwork cost, loss of cultivable area to the risers, unsuitability on shallow soils (where cutting exposes bed-rock) and on excessively steep slopes. Precautions against failure: protect and grass the risers, provide stable outlets and grassed waterways, line the inward drains, avoid over-steep batters, ensure cut equals fill with proper compaction, and maintain carefully through the first one or two monsoons.

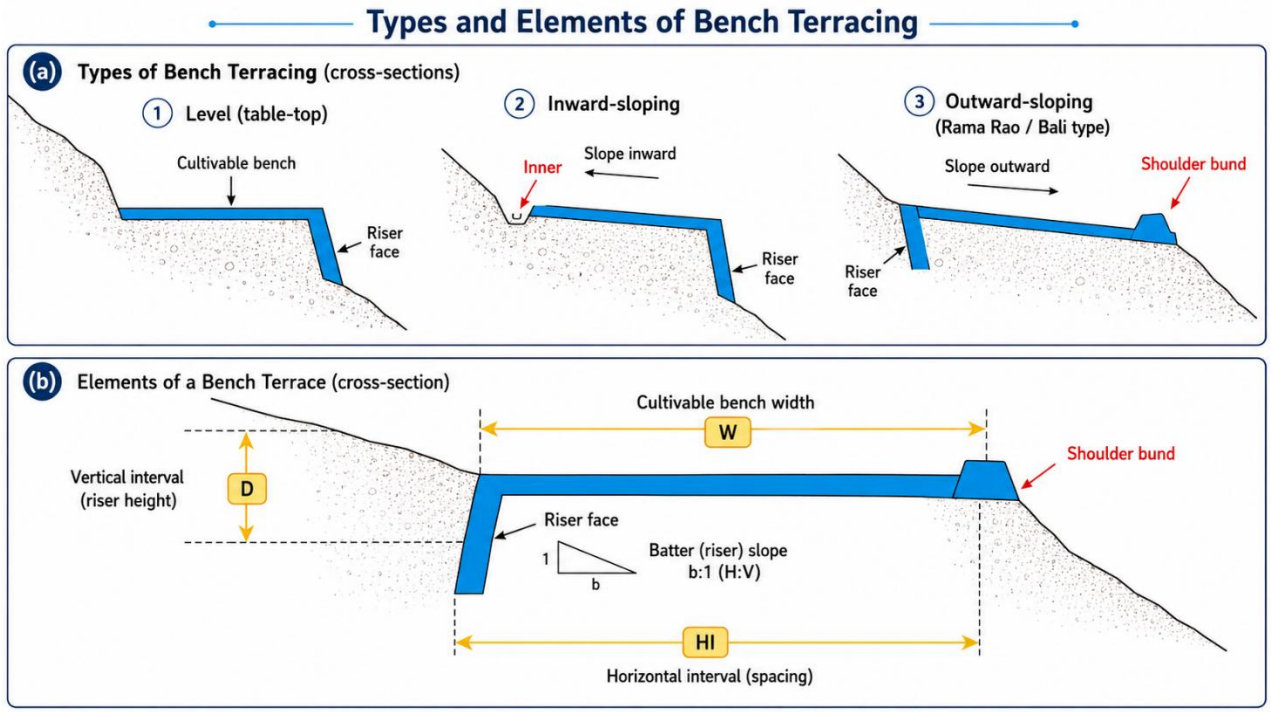
Precautions to avoid failure: provide a safe outlet/grassed waterway; maintain correct grade; protect risers with grass; avoid over-steep batters; ensure cut = fill and proper compaction.

7.1 Classification (Rama Rao / Bali) — by slope of the bench

© Hornbill Classes
+91 78802-71423 Hornbillclasses@gmail.com

Type	Bench surface	Suitability
Level (table-top)	Bench exactly level	Medium-rainfall areas; paddy and moisture conservation
Sloping inward	Bench slopes inward (1 in 10–50) to an inner drain	High-rainfall areas; safe disposal of excess runoff
Sloping outward	Bench slopes gently outward, with a shoulder bund	Low-rainfall, permeable soils; gentler slopes

Rama Rao classified bench terraces for Indian conditions on this rainfall/slope basis — outward-sloping for low rainfall, inward-sloping for high rainfall, and level for moderate rainfall and paddy.



7.2 Area lost due to bench terracing — derivation

Full question (IFoS 2023 | P1/2(c) | 20M). Derive the expression for area lost in percentage for cultivation due to construction of bench terrace under the following conditions: (i) Batter slope 1:1, (ii) Batter slope ½:1.

∑ DERIVATION — % area lost (batter 1:1 and ½:1)

Set-up. Land slope S%; vertical interval (riser height) = D; batter slope = b:1 (b horizontal per 1 vertical). The sloping riser face is not cultivable; the flat bench of width W is.

Geometry.

Horizontal interval $HI = 100 \cdot D/S.$

The riser's horizontal projection $= b \cdot D,$

so the cultivable bench width

$W = HI - b \cdot D.$

Area lost (per horizontal interval, unit contour length):

$\%\ area\ lost = (b \cdot D\ /\ HI) \times 100$

$= (b \cdot D \cdot S)/(100 \cdot D) \times 100 = b \cdot S$

Apply the two batters.

Batter 1:1 ($b = 1$): % area lost = S.

Batter ½:1 ($b = 0.5$): % area lost = S/2.

Answer. % area lost = b·S. For batter 1:1 it equals the land slope S (%);

for batter ½:1 it equals S/2 (%).

Flatter batters (1:1) project further horizontally and so lose MORE land than steeper ones (½:1). Equivalent form: % area lost = b·D/(W + b·D) × 100.

∑ DERIVATION — Length & earthwork per hectare

Length of terrace per hectare = (plan area)/(terrace spacing) = 10 000 / HI (m per ha), with ***HI = 100·D/S.***

Earthwork (cut = fill). Setting the level bench at the mid-height D/2 (so cut = fill), the ground line crosses that level exactly at the midpoint of the run; the cut region is therefore a smaller triangle similar to the full HI×D wedge but scaled by ½ in each dimension — base HI/2 and height D/2:

= ½·(HI/2)·(D/2) = HI·D/8 per unit length.

Over a hectare this reduces to the standard result:

Earthwork (cut) per ha = HI·D/8 × (10 000/HI) = 1 250·D (m^3/ha)

7.3 Worked problems — bench terraces

⌘ Length, earthwork & area lost

Full question. Bench terraces are to be built on a 20% hill slope. If the vertical interval is 2 m, determine (i) length per hectare, (ii) earthwork, (iii) area lost — for vertical cut and for a batter of 1:1. (Cut = fill.) [IFoS 2017 | P1/4(c) | 10M]

Step 1 : Horizontal interval & cultivable width.

HI = 100·D/S = 100×2/20 = 10 m; W (batter 1:1) = HI − D = 10 − 2 = 8 m.

Step 2 : ***(i) Length per hectare. 10 000/HI = 10 000/10 = 1 000 m/ha.***

Step 3 : (ii) Earthwork (cut = fill);

cut cross-section = ***HI·D/8. = 10×2/8 = 2.5 m^2/m;***

earthwork = 2.5×1 000 = 2 500 m^3/ha.

Step 4 : (iii) Area lost.

Vertical cut: 0% (no riser projection). Batter 1:1: b·S = 1×20 = 20%.

Answer. (i) 1000 m/ha; (ii) ≈ 2500 m^3/ha; (iii) 0% for a vertical cut, 20% for a 1:1 batter.

⌘ Inward-sloping bench terrace design

Full question. Design a 150 m long inward-sloping (5%) bench terrace for a sandy-loam soil of average slope 15%. The entire terrace width acts as a channel of uniform grade 0.6%. Rainfall intensity for the return period and time of concentration = 20 cm/h, runoff coefficient = 0.3, riser side slope 1:1, shoulder-bund height 30 cm, bottom width 75 cm, side slope 1:1, n = 0.04, VI = 1.06 m, terrace area = 0.09 ha. [IFoS 2016 | P1/3(c) | 20M]

Step 1 : Terrace geometry.

HI = 100·VI/S = 100×1.06/15 = 7.07 m;

cultivable width W = HI − b·VI = 7.07 − 1.06 ≈ 6.0 m.

Step 2 : Design peak runoff (rational method).

© Hornbill Classes
+91 78802-71423 Hornbillclasses@gmail.com

$Q = C \cdot i \cdot A/360 = 0.3 \times 200\ mm/h \times 0.09\ ha/360 = 0.015\ m^3/s.$

Step 3 : Channel check (whole bench as channel, ***grade 0.6%, n = 0.04***). The 6 m-wide inward-sloping bench acting as a shallow channel at 0.6% carries $0.015\ m^3/s$ with only a few centimetres of flow depth — well within the ***30 cm shoulder bund.***

***Answer. Terrace*: VI 1.06 *m*, *HI* ≈ 7.07 m, cultivable width ≈ 6 m, inward-sloping at 5% to an inner drain that carries the design runoff (≈ 0.015 m³/s) safely at 0.6% grade behind a 0.30 m shoulder bund. % area lost = b·S = 1×15 = 15%.**

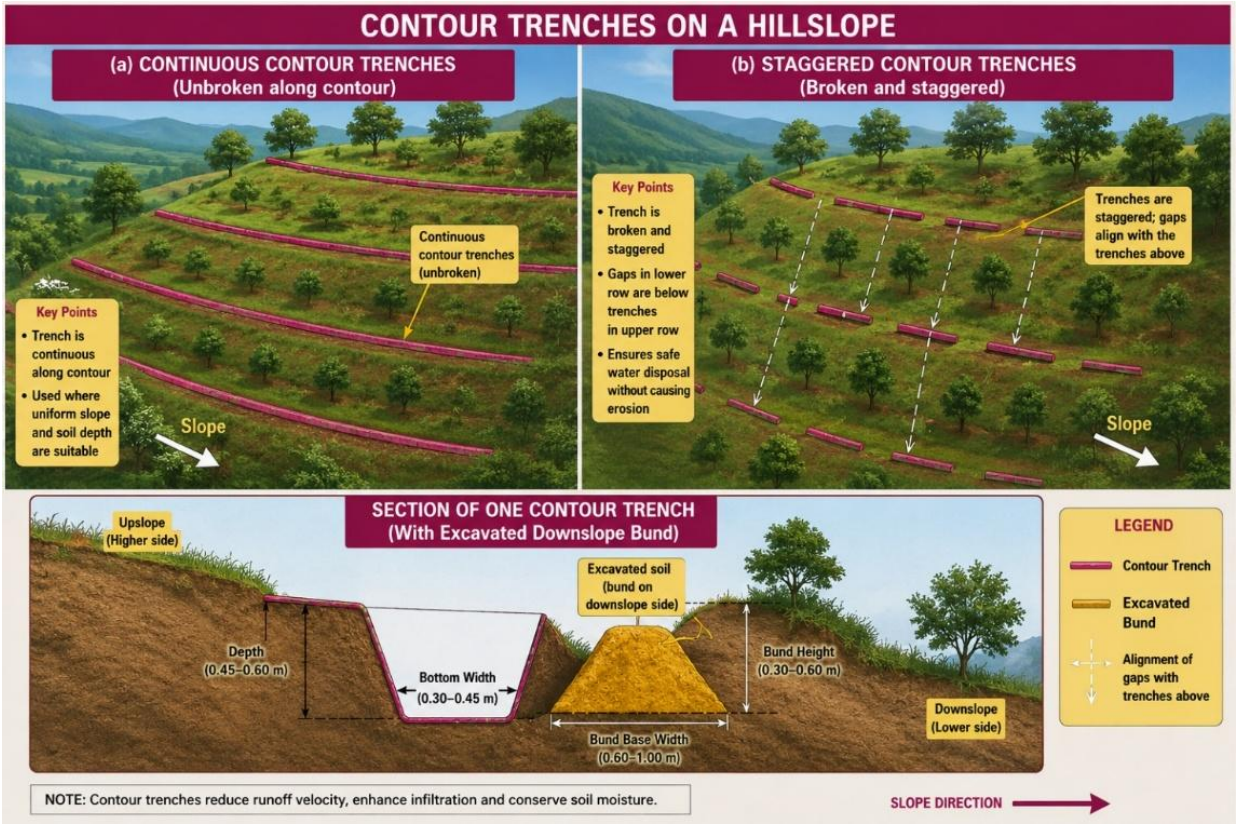
Source — Mishra & Bal, L5 (Terracing), p.31–38; Gully & Ravine Control Structures, L23, p.184–191.

8. OTHER TERRACES & CONTOUR TRENCHES

PREVIOUS YEAR QUESTIONS

- Differentiate continuous contour trench and staggered contour trench.*** [IFoS 2022 | P1/1(a) | 8M]
- hat is a contour trench? Types and design procedure of contour-trench systems. ***
  [IFoS 2018 | P1/2(d) | 10M]

Besides the bench terrace, two other slope-breaking measures. A broad-base (channel) terrace is a low, wide ridge-and-channel built across gentle land (< ~10%) over which the whole section can still be farmed — unlike the bench terrace, it does not step the slope. Graded (channel) terraces dispose of runoff at a safe velocity; level (ridge) terraces conserve it. The second measure, the contour trench, is widely used on hill slopes, wastelands and afforestation sites.



A contour trench is a trench dug along the contour to intercept runoff, store it for infiltration (moisture conservation) and check erosion by breaking the slope length. The excavated soil is placed on the downhill side as a small bund and stabilised with vegetation.

Type	Description & use
Continuous contour trench (CCT)	An unbroken trench along the whole contour; gives maximum interception and infiltration; used for moisture conservation in low-rainfall areas and on uniform slopes for afforestation.
Staggered contour trench (SCT)	Short trenches with gaps, the trenches of one row set opposite the gaps of the next (staggered); excess water passes safely through the gaps, so the layout is safer against breaching and is used in higher-rainfall areas and on irregular, erodible slopes.

Design procedure of a contour-trench system (IFoS 2018)

- fix the vertical/horizontal spacing of trenches from the slope and rainfall (closer on steeper, more erodible land).
- size the trench cross-section to store the design runoff between trenches (cross-section area × length = runoff volume).
- choose a continuous (low-rainfall) or staggered (high-rainfall) layout; place the spoil as a downslope bund.
- stabilise the bund and trench with vegetation and provide safe disposal for any overflow.

9. CONTOUR STONE WALLS & CONSERVATION DITCHES

PREVIOUS YEAR QUESTIONS

- State the adoptability and functions of conservation ditches and contour stone walls for control of soil erosion *** [IFoS 2025 | P1/1(c) | 8M]

On stony, shallow-soil hill terrain where earthen bunds are impractical, two simple measures take their place. A contour stone wall is a low dry-stone wall built along the contour from locally available stones; being permeable it does not impound water dangerously, yet it breaks the slope length, checks runoff velocity, traps sediment and demarcates fields. A conservation (or diversion) ditch is an excavated, graded channel that intercepts and diverts runoff coming from above an erodible field, a terrace or a gully head, and leads it safely to a stable outlet, protecting the land below.

Measure	Adoptability	Functions
Contour stone wall	Stony, shallow-soil hill areas where stones are freely available and earthen bunds are impractical; labour cheap.	Breaks slope length, checks velocity, traps sediment, permeable (no dangerous impounding), reuses local stone, demarcates fields.
Conservation / diversion ditch	Above erodible fields, gully heads and terraces, to intercept upslope runoff.	Diverts runoff to a safe outlet, protects the land and structures below, and checks gully advance.

Source — Soil & Water Conservation Structures, L30 (Diversions & Ditches), p.261–269.

10. GRASSED WATERWAYS — DESIGN

PREVIOUS YEAR QUESTIONS

- Design a trapezoidal grassed waterway (Q=4 m^3/s, 0.3%, n=0.04, Z=2:1). *** [IFoS 2023 | P1/3(b) | 15M]
- Design a parabolic waterway (Q=3 m^3/s, 4%, dub grass, v≤2.5 m/s). *** [IFoS 2021 | P1/1(e) | 8M]
- Design a parabolic grassed waterway (Q=2.6 m^3/s, 3%, v=1.75, n=0.04). *** [IFoS 2017 | P1/3(b) | 10M]
- Design a parabolic grassed waterway (Q=3 m^3/s, 4%, dub grass, n=0.04). *** [IFoS 2016 | P1/4(c) | 20M]
- Design a parabolic grassed waterway (Q=6 m^3/s, 1%, sandy, v=1.5, n=0.034).

[OPSC-CSE 2023 | Q.15(b) | 20M]

© Hornbill Classes
+91 78802-71423 Hornbillclasses@gmail.com

A grassed waterway is a natural or constructed channel, lined with erosion-resistant grass, that conveys the runoff collected by terraces, bunds and diversions down the slope to a safe outlet without scouring. The grass cover holds the soil and keeps the flow velocity non-erosive, while also filtering sediment. It is the standard 'outlet' that makes graded bunds and terraces safe, and is therefore one of the highest-frequency numerical topics in the paper. Cross-sections are parabolic (the natural and preferred shape), trapezoidal or triangular. The channel is sized to carry the design peak runoff Q at or below the permissible (non-erosive) velocity v for the grass and soil, using Manning's formula.

$$A = Q / v \qquad v = (1/n)\cdot R^{(2/3)}\cdot S^{(1/2)} \Rightarrow R = (v\cdot n / \sqrt{S})^{(3/2)}$$

∑ DERIVATION — Parabolic-waterway section relations

For a shallow parabolic channel of top width T and flow depth D, the cross-sectional area is

$$A = (2/3)\cdot T\cdot D,$$

and because the channel is wide and shallow the wetted perimeter P ≈ T, so the hydraulic radius

$$R = A/P \approx (2/3)D.$$

$$R \approx 2D/3 \Rightarrow D = 3R/2$$

$$A = (2/3)\cdot T\cdot D \Rightarrow T = 3A/(2D)$$

Design route: from the permissible velocity get $A = Q/v$; from Manning get R, hence $D = 3R/2$ and $T = 3A/(2D)$;

finally add **15–20% (≈15 *cm*)** free board to the depth and check that the velocity does not exceed the permissible value.



10.1 Worked problems — grassed waterways

⌘ Parabolic waterway (dub grass)

Full question. Design a parabolic waterway to carry 3 m^3/s down a 4% slope. An excellent stand of dub grass is to be maintained; the maximum permissible velocity is 2.5 m/s. Draw the parabolic cross-section. [IFoS 2021.P1/1(e)·8M]

Given:

- ***Design discharge*, Q = 3 m^3/s**
- ***Channel slope*, S = 4%**
- ***Grass cover = excellent stand of dub grass***
- ***Maximum permissible velocity*, v = 2.5 m/s**
- ***Manning's n* = 0.04**

Step 1 : Required area

$A = Q/v = 3/2.5 = 1.20\ m^2$.

Step 2 : Hydraulic radius (n = 0.04, S = 0.04).

$R = (v \cdot n/\sqrt{S})^{1.5}$

$= (2.5 \times 0.04/0.20)^{1.5} = (0.50)^{1.5} = 0.354\ m$.

Step 3 : Depth & top width.

$Depth\ D = 3R/2 = 0.53\ m$;

$Top\ width\ T = 3A/(2D) = 3 \times 1.20/(2 \times 0.53) = 3.39\ m$.

Answer. **Parabolic waterway: top width T ≈ 3.39 m, design depth D ≈ 0.53 m (add ~0.15 m free board ⇒ ≈ 0.68 m). Velocity 2.5 m/s is at the permissible limit for dub grass.**

⌘ Parabolic waterway (v = 1.75 m/s)

Full question. Design a parabolic grassed waterway to carry 2.6 m^3/s down a 3% slope; a good grass stand allows a velocity of 1.75 m/s. Take n = 0.04. [IFoS 2017 | P1/3(b) | 10M]

Given:

- ***Design discharge*, Q = 2.6 m^3/s**
- ***Channel slope*, S = 3%**
- ***Grass cover = good stand, permissible velocity* v = 1.75 m/s**
- ***Manning's n* = 0.04**

Step 1 : Area.

$A = Q/v$

$= 2.6/1.75 = 1.49\ m^2$.

Step 2 : Hydraulic radius (n = 0.04, S = 0.03).

$R = (v \cdot n/\sqrt{S})^{1.5}$

$R = (1.75 \times 0.04/\sqrt{0.03})^{1.5}$

$R = (0.404)^{1.5} = 0.257\ m$.

Step 3 : Depth & top width. $D = 3R/2 = 0.385\ m$; $T = 3A/(2D) = 3 \times 1.49/(2 \times 0.385) = 5.80\ m$.

Answer. **Parabolic waterway: top width ≈ 5.8 m, depth ≈ 0.39 m (+ ~0.15 m free board ≈ 0.54 m).**

⌘ Parabolic waterway (Q = 3 m^3/s, 4%)

Full question. Design a parabolic grassed waterway to carry 3 m^3/s down a 4% slope; an excellent stand of dub grass is to be maintained. Take n = 0.04. [IFoS 2016 | P1/4(c) | 20M]

Given:

- ***Design discharge*, Q = 3 m^3/s**
- ***Channel slope*, S = 4%**
- ***Grass cover = excellent stand of dub grass (⇒ permissible velocity ≈ 2.5 m/s)***

© Hornbill Classes
+91 78802-71423 Hornbillclasses@gmail.com

- ***Manning's n = 0.04***

Step 1 : Permissible velocity for dub grass ≈ 2.5 m/s ⇒

$A = Q/v$

$= 3/2.5 = 1.20\ m^2$.

Step 2 : Hydraulic radius.

$R = (v \cdot n/\sqrt{S})^{1.5}$

$R = (2.5 \times 0.04/\sqrt{0.04})^{1.5} = (0.50)^{1.5} = 0.354\ m$.

Step 3 : Depth & top width. $D = 3R/2$ = 0.53 m; $T = 3A/(2D)$ = 3.39 m.

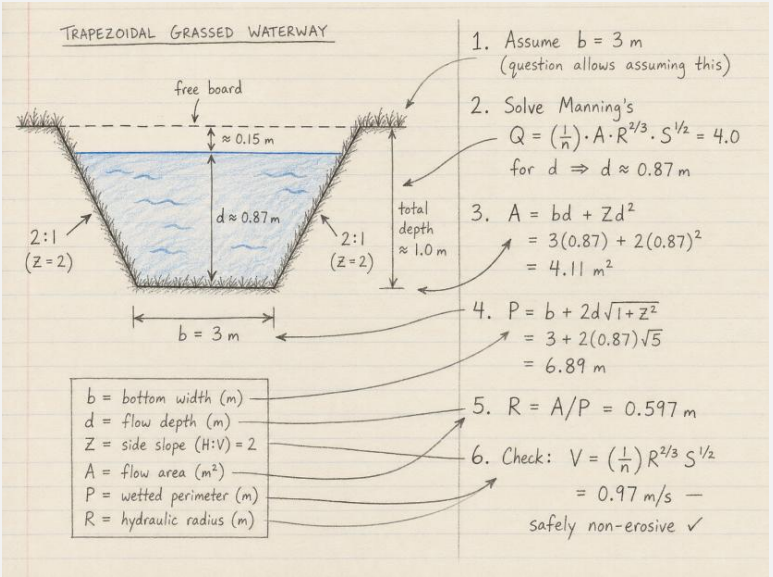
Answer. **Identical to the 2021 problem (same Q, S, n, grass): top width ≈ 3.39 m, depth ≈ 0.53 m (+ free board). Velocity 2.5 m/s ≤ permissible for dub grass.**

⌘ Trapezoidal grassed waterway

Full question. Design a trapezoidal grassed waterway: peak runoff Q = 4.0 m³/s, grade 0.3%, n = 0.04, side slope Z = 2:1 (H:V). Assume other necessary data. [IFoS 2023 | P1/3(b) | 15M]

Given:

- ***Design discharge, Q = 4.0 m³/s***
- ***Channel grade, S = 0.3%***
- ***Manning's n = 0.04***
- ***Side slope, Z = 2:1 (H:V)***
- ***Bottom width not given — assumed in the solution***



Step 1 : Assume a bottom width and solve Manning for depth. With b = 3 m, Z = 2, n = 0.04, S = 0.003, solving

$Q = (1/n) \cdot A \cdot R^{(2/3)} \cdot S^{(1/2)} = 4.0$ *gives* $d \approx 0.87\ m$.

$A = bd + Zd^2 = 3(0.87) + 2(0.87)^2 = 4.11\ m^2$;

Wetted Perimeter $P = b + 2d\sqrt{(1+Z^2)}$

$= 3 + 2(0.87)\sqrt{5} = 6.89\ m$;

Hydraulic Radius $R = A/P = 0.597\ m$.

Step 2 : Check velocity.

$v = (1/n) \cdot R^{(2/3)} \cdot S^{(1/2)}$

$V = (1/0.04)\ (0.597)^{(2/3)}\ (0.003)^{(1/2)} = 25 \times 0.709 \times 0.0548 = 0.97\ m/s$;

$Q = A \cdot V \approx 4.0\ m^3/s$ ✓.

Answer. **Trapezoidal waterway: bottom width 3 m, flow depth ≈ 0.87 m (+ ~0.15 m free board ⇒ ≈ 1.0 m), side slope 2:1. Velocity ≈ 0.97 m/s is safely non-erosive. (Bottom width assumed, as the question permits.)**

⌘ Parabolic waterway (State PSC)

Full question. Design a parabolic grassed waterway to carry a peak flow of 6 m³/s on a 1% slope on erodible sandy soil; good grass cover allows a permissible velocity of 1.5 m/s. Take n = 0.034. [OPSC-CSE 2023 | Q.15(b) | 20M]

Given:

- ***Design discharge, Q = 6 m³/s***
- ***Channel slope, S = 1%***

- ***Soil type = erodible sandy soil***
- ***Grass cover = good, permissible velocity $v = 1.5\ m/s$***
- ***Manning's $n = 0.034$***

Step 1 : Area.

$A = Q/v = 6/1.5 = 4.0\ m^2$.

Step 2 : Hydraulic radius (n = 0.034, S = 0.01).

$R = (v \cdot n/\sqrt{S})^{1.5}$

$R = (1.5 \times 0.034/\sqrt{0.01})^{1.5} = (0.51)^{1.5} = 0.364\ m$.

Step 3 : Depth & top width.

$D = 3R/2$ = 0.546 m;

$T = 3A/(2D)$ = 3×4.0 / (2×0.546) = 11.0 m.

Answer. Parabolic waterway: top width ≈ 11 m, depth ≈ 0.55 m (+ free board). Velocity 1.5 m/s suits erodible sandy soil under good grass.

11. WIND BREAKS & SHELTER BELTS

PREVIOUS YEAR QUESTIONS

- Design factors and layout to install a shelter-belt against wind erosion.*** [IFoS 2019 | P1/3(a) | 10M]
- Calculate the spacing between shelter-belts (H=15 m, Va=18, Vt=9 kmph, deviation 10°). *** [IFoS 2021 | P1/2(b·i) | 10M]
- Wind-erosion factors; wind-break and shelter-belt practices. [UK·PSC 2021 | Q.1(iv) | 10M]

Wind breaks and shelter belts are barriers of trees and shrubs (often with a grass understorey) planted across the prevailing wind to reduce its velocity near the ground and so control wind erosion, evaporation and crop damage. A wind break is a narrow barrier of one or two rows protecting a farmstead or a small field; a shelter belt is a wider, multi-row belt protecting a large area of cropland. Both reduce wind velocity, trap drifting soil and conserve soil moisture on the leeward side.

DESIGN FACTORS & LAYOUT (IFOS 2019)

- **Height (H) :** the key parameter; the protected leeward distance scales with barrier height, about 10–20 times the height (≈ 17 H).
- **Orientation :** the belt is aligned perpendicular (at right angles) to the prevailing wind for maximum effect; a deviation angle reduces the protected distance.
- **Density / permeability :** a semi-permeable belt (≈ 40–60% density) is best — it diffuses the wind and protects a longer leeward distance, whereas a solid barrier creates sharp eddies and a short shelter.
- **Width & composition :** several rows — tall trees in the centre flanked by shrubs — giving a graded, triangular, durable profile of hardy, deep-rooted, fast-growing species.
- **Length & layout :** long (> ~12 H) and continuous to avoid funnelling at gaps; main belts across the wind at the design spacing, with subsidiary belts at right angles.

SPACING OF SHELTER BELTS

The spacing (protected distance) between successive belts follows from the height, the prevailing and threshold wind velocities and the angle of deviation:

$$D = 17 \cdot H \mid (Vt / Va) \mid \cos\theta$$

© Hornbill Classes
+91 78802-71423 Hornbillclasses@gmail.com

where D = spacing/protected distance, H = belt height, Vt = threshold (non-erosive) wind velocity, Va = actual prevailing wind velocity, and θ = angle of deviation of the wind from the perpendicular to the belt. The factor 17 reflects the ~10–20 H protected distance.

⌘ Spacing of shelter belts

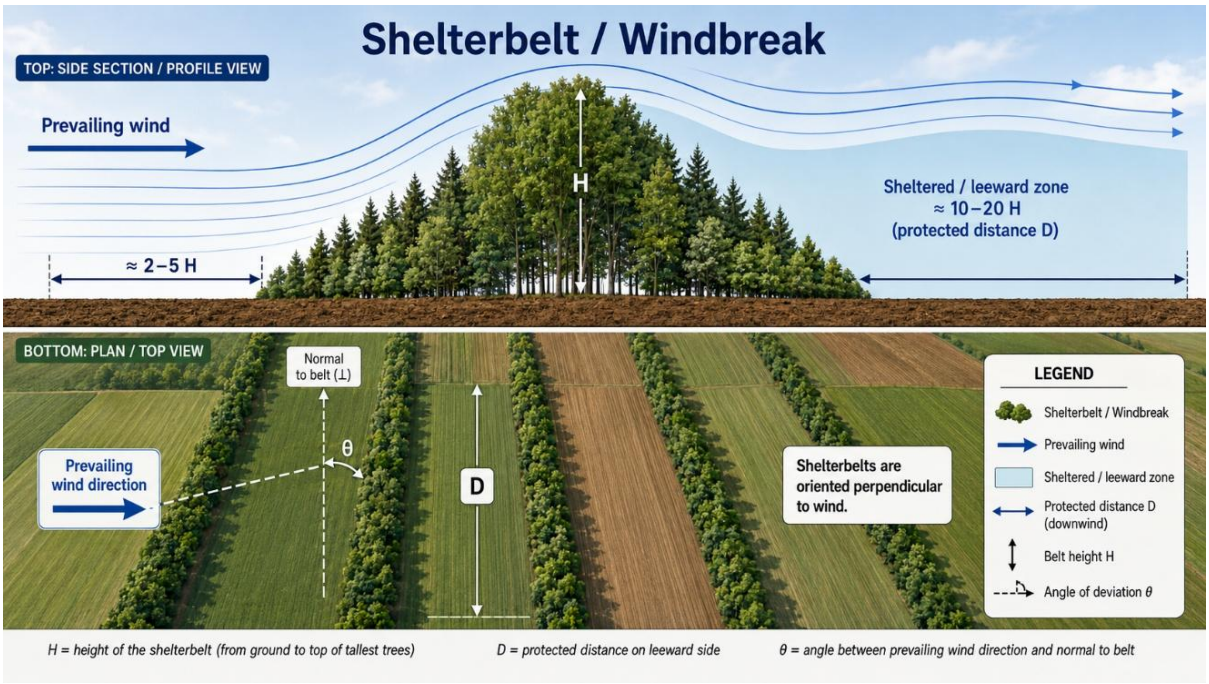
Full question. Calculate the spacing between shelter-belts of height 15 m. The actual wind velocity at 15 m is 18 kmph and the threshold wind velocity at 15 m is 9 kmph. The angle of deviation of the prevailing wind from the perpendicular to the belt is 10°. [IFoS 2021 | P1/2(b·i) | 10M]

Concept. A belt protects a leeward distance of roughly 17 times its height when the wind is perpendicular; the protection is reduced when the actual velocity Va exceeds the threshold Vt and when the wind deviates by an angle θ from the perpendicular.

Substitute into D = 17·H·(Vt/Va)·cos θ. = 17×15×(9/18)×cos 10° = 255×0.5×0.9848 = 255×0.4924 = 125.6 m.

Answer. Spacing between shelter belts ≈ 126 m.

The 17H coefficient and the velocity/angle correction follow the standard convention; the supplied books treat shelter belts qualitatively, so the spacing relation is grounded via ICAR e-course / TNAU, per charter.



12. LAND-USE CAPABILITY CLASSIFICATION

PREVIOUS YEAR QUESTIONS

- Soil-conservation farming practices for land under capability Class II.*** [IFoS 2023 | P1/2(a) | 15M]
- Land-capability classification — components, measures, suitability and limits of each class & sub-class. *** [OPSC·CSE 2020 | Q.6(c)(i) | 8M]
- Land-capability classification and its modifications under Indian conditions. [OPSC·CSE 2017 | Q.7(a) | 15M]
- Land-use capability classification in Indian conditions. [OPSC·CSE 2016 | Q.5(c) | 20M]

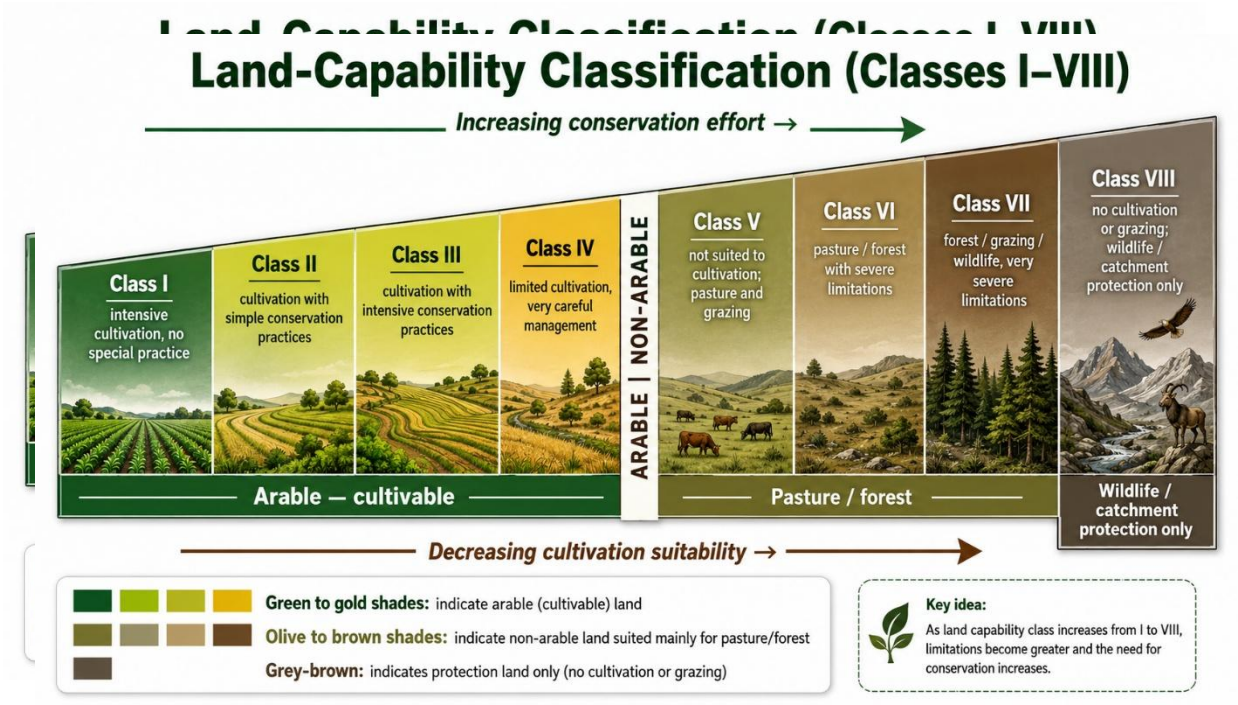
The land-capability classification groups land into eight capability classes (I–VIII) according to its ability to sustain use without erosion or degradation, so that every parcel is put to its safest productive use. Developed by the US Soil Conservation Service and adapted for Indian conditions, it is the framework that ties together all the

measures of this chapter: Classes I–IV are arable (cultivable), Classes V–VIII are non-arable (grazing, forestry, wildlife). Capability decreases — and the limitations and conservation needs increase — from Class I down to Class VIII.

Class	Capability	Use & conservation
I	Very good, nearly level land; no/slight limitations	Any crop; ordinary good management
II	Good land, gentle slope, slight erosion/wetness	Cultivable with simple practices — contour farming, strip cropping, cover crops, bunding
III	Moderate limitations, moderate slope/erosion	Cultivable with intensive measures — terracing, bunding, waterways
IV	Severe limitations, steep/erodible	Occasional/limited cultivation; mostly perennial vegetation with strong measures
V	Not erodible but other limits (wet, stony)	Not arable; pasture/forestry; no erosion hazard
VI	Moderate-to-severe limitations	Grazing and forestry with conservation
VII	Very severe limitations	Restricted grazing/forestry; afforestation
VIII	Extreme limitations	Wildlife, recreation, watershed/catchment protection only

CAPABILITY SUB-CLASSES (LIMITATION SYMBOLS)

Each class (except I) carries a sub-class letter for the dominant limitation: e = erosion/run-off hazard; w = excess water/wetness/drainage; s = soil/root-zone limitation (shallow, stony, low fertility); c = climatic limitation. For example, IIe is good land limited mainly by erosion.



INDIAN MODIFICATIONS

Under Indian conditions the USDA system is adapted to the monsoon climate, small holdings and high rainfall intensity with greater emphasis on the erosion (e) sub-class, an additional land-irrigability classification for command areas, and full integration with watershed planning. The eight classes and the e/w/s/c symbols are retained but mapped to local soils, slopes and rainfall.

© Hornbill Classes
+91 78802-71423 Hornbillclasses@gmail.com

MODEL ANSWER — Conservation farming for Class II (IFoS 2023)[***]
Recommended practices for Class II land: contour cultivation, contour strip cropping, cover and green-manure crops, conservation tillage with residue retention, suitable crop rotations, grassed waterways for safe disposal, simple drainage where wetness is the limitation, and — where needed — light mechanical support such as contour bunds. Class II land is cultivable for all common crops with these slight-to-moderate measures, the aim being to keep soil loss within the permissible limit while maintaining fertility and organic matter.

13. ALLIED NOTES — CATCHMENT-AREA TREATMENT & NALLA BUNDING

PREVIOUS YEAR QUESTIONS

Catchment-Area Treatment and allied conservation notes. [IFoS 2017 | P1/4(b) | short note]

These short-note items recur across papers and tie the chapter's measures into whole-catchment planning; they cross-reference the watershed and gully-control chapters.

- **Catchment-Area Treatment (CAT) :** the integrated application of soil-and-water-conservation measures — afforestation, pasture development, agronomic and vegetative works, bunding, contour measures, drainage-line and gully-control treatment — over the entire catchment of a reservoir or project, to reduce erosion and sediment yield and so prolong the project's life. A key component of watershed and reservoir management.
- **Nalla bunding :** small earthen or masonry bunds built across minor streams (nallas) to check flow velocity, trap sediment and recharge groundwater; a drainage-line treatment within CAT.
- **Allied cross-references :** the grassed waterway (§10), agronomic measures (§2), the USLE and flood routing are cross-referenced to their dedicated chapters/sections.

14. PYQ COVERAGE MATRIX

Every in-scope past question from the attached PYQ file (30 IFoS 2016–2025 + 15 State PSC, clustered into seven themes) maps to a section above. Numerical-bearing clusters are marked.

§	Section	Cluster	# PYQs	Numerical?
1	Scope & classification of conservation measures	A–G	2	—
2	Agronomic & tillage measures	E	2	—
3	Strip cropping	E	3	—
4	Vegetative measures & wattling	E	3	—
5	Contour bunds — design	A	9	yes
6	Graded bunds — design	A	2	yes
7	Bench terraces — types, design, area lost	C	6	yes
8	Other terraces & contour trenches	C/F	2	yes
9	Contour stone walls & conservation ditches	F	1	—
10	Grassed waterways — design	B	6	yes
11	Wind breaks & shelter belts	G	3	yes
12	Land-use capability classification	D	5	—

Coverage: 12 sections, all 45 in-scope PYQs mapped, zero unmapped. Several bund/terrace/waterway questions touch two sections (design + area-lost), giving more section-hits than questions.s

15. QUICK-REVISION FORMULA SHEET

Every design relation in this chapter, in one place. Units are SI; conventional units are noted where used in the worked problems.

#	Quantity	Formula	Notes
1	Bund vertical interval (Cox)	VI = 0.3 (X·S/3 + Y) m	S in %; X = rainfall index (0.4–0.8), Y = cover index (1.0–2.0)
2	Bund vertical interval (Ramser)	VI = 0.305 (S/3 + 2) m	older alternative to Cox
3	Horizontal interval	HI = 100·VI / S (m)	spacing along the ground; S in %
4	Water depth behind bund	d = √(2·Pe·VI)	Pe = design excess-rainfall depth (m)
5	Bund / terrace height	H = d + free board	free board ≈ 10–20% of H, or 15 cm
6	Bund base width	B = T + 2·n·H	T = top width, n:1 = side slope
7	% area lost (bund)	= base width / HI	express as %
8	Surplus-weir length	L = Q / (C_w·$H^{(3/2)}$)	C_w ≈ 1.7 SI; H = head over crest
9	Manning's (channel)	Q = (1/n)·A·$R^{(2/3)}$·$S^{(1/2)}$, R = A/P	graded bunds & waterways
10	Peak runoff (rational)	Q = C·i·A / 360	i in mm/h, A in ha ⇒ Q in m^3/s
11	Bench % area lost	= b·S	b:1 batter; 1:1 ⇒ S, ½:1 ⇒ S/2
12	Bench length per ha	= 10 000 / HI (m/ha)	HI = 100·D/S
13	Bench earthwork (cut=fill)	= 1 250·D (m^3/ha)	D = vertical interval (m)
14	Parabolic waterway	R ≈ 2D/3 ⇒ D = 3R/2; T = 3A/(2D)	A = Q/v; R = $(v·n/\sqrt{S})^{(3/2)}$
15	Shelter-belt spacing	D = 17·H·(Vt/Va)·cos θ	Vt = threshold, Va = actual wind velocity

© Hornbill Classes
+91 78802-71423 Hornbillclasses@gmail.com

CHAPTER

3

GULLY CONTROL & PERMANENT STRUCTURES

Drop | chute | drop-inlet spillways | check dams | farm & percolation ponds | waste weirs | trickle & flood spillways | wing walls, levees & retards | stability of retaining walls & gravity dams

OFFICIAL SYLLABUS — Chapter 3 scope

Gully control structures (temporary and permanent). Design of permanent soil-conservation structures — **drop spillway, chute spillway and drop-inlet pipe spillway**. Design of **farm ponds and percolation ponds**. **Stability analysis of retention walls and dams**. Wing walls, levees, retards and waste weirs. Design of **trickle and flood spillways for earth dams**.

Chapter Outline

1. **Scope, Gully Erosion & Classification of Control Structures**
2. **Gully Control — Principles, Biological & Temporary Measures**
3. **Permanent Soil-Conservation Structures — Design Framework**
4. **Drop Spillway — Theory, Design & Structural Stability**
5. **Chute Spillway & SAF Stilling Basin**
6. **Drop-Inlet (Pipe) Spillway**
7. **Trickle & Flood Spillways for Earth Dams**
8. **Check Dams — Planning & Design**
9. **Farm Ponds — Types, Site Selection, Design & Capacity**
10. **Percolation Ponds & Percolation Tanks**
11. **Waste / Surplus Weir — Design**
12. **Wing Walls, Levees, Retards & Appurtenances**
13. **Stability Analysis — Retaining Walls & Gravity Dams**
14. **Watershed Hydrology for Design & Allied State-PSC Numericals**
15. **PYQ Coverage Matrix**
16. **Quick-Revision Formula Sheet**

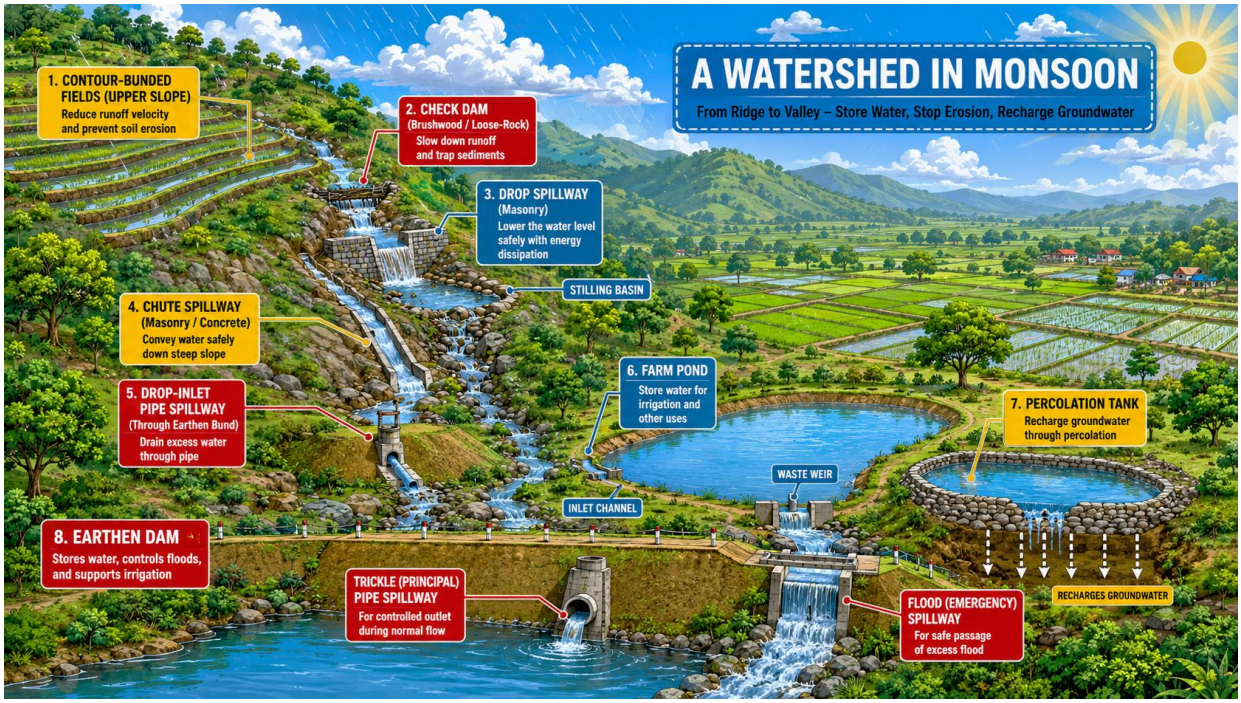
◆ WEIGHTAGE & TREND ANALYSIS (IFOS 2016–2025)

Chapter 3 is one of the ***highest-yielding topics*** of Paper I, Section A. Between 2016 and 2025 the IFoS examination has drawn **22 questions** from this chapter, with a further 18 from the State forest / engineering services (OPSC, UK-PSC). The design of **permanent gully-control spillways and farm ponds** dominates the trend, and roughly half of all questions are numerical.

Theme	IFoS Qs	Typical form	Priority
Drop spillway	11	Design + parts + numerical	★★★
Gully control methods	10	Descriptive + steps	★★★
Chute & drop-inlet spillways	7	Design features + pipe/box numerical	★★
Farm ponds & percolation	7	Types + capacity numerical	★★
Stability (walls / gravity dam)	3	Derivation + 30-M numerical	★★
Trickle & flood spillway	2	Requirements & features	★★
Check dams	2	Uses + planning + design	★
Wing walls, levees, retards, waste weir	3	Short notes + weir numerical	★

© Hornbill Classes
+91 78802-71423 Hornbillclasses@gmail.com

Reading strategy. *Master the drop spillway completely (theory + full design + stability) — it alone fetches one in every five marks from this chapter, and its design logic carries straight over to the chute and drop-inlet spillways.*



1. SCOPE, GULLY EROSION & CLASSIFICATION OF CONTROL STRUCTURES

PREVIOUS YEAR QUESTIONS

- Gully erosion; discuss stages and classification of gullies; conditions under which permanent gully-control structures are recommended.*** [OPSC·CSE 2024-25 | P1 Q13 | 20M]
- Classify soil-conservation structures into various categories.*** [OPSC·Forest 2015-16 | P1 Q3(a) | 10M]

Chapter 1 traced the processes and agents of erosion; Chapter 2 supplied the biological and mechanical measures that hold sheet and rill erosion within the permissible soil-loss limit. One problem still survives wherever runoff has already concentrated into a defined channel: the ***gully***. This chapter takes on that concentrated-flow erosion with engineering structures.

1.1 THE GULLY AS AN ENGINEERING SITE

A ***gully*** is a channel or miniature valley cut by concentrated runoff, through which water flows only during and immediately after heavy rain. It is the advanced stage of the sequence **sheet → rill → gully → ravine**, the distinction being essentially size: a gully is too large to be obliterated by ordinary tillage, whereas a **ravine** is a still deeper, wider gorge. About 4 million hectares of India are gully- and ravine-affected, chiefly in the Chambal–Yamuna belt.

1.2 DEVELOPMENT STAGES OF A GULLY

Two erosive actions build a gully together — **waterfall (over-fall) erosion** advances the head upslope, while **channel erosion** scours the bed and banks. Its life passes through four stages:

- **Formation stage :** scour of the top-soil begins along the line of concentrated flow; proceeds slowly while the resistant top-soil lasts.

- **Development stage :** the head cuts back upslope and the channel deepens rapidly into the weaker sub-soil (C-horizon); most soil loss occurs here.
- **Healing stage :** vegetation begins to colonise the gully as the grade flattens.
- **Stabilisation stage :** a stable gradient and bank slope are reached and a vegetal cover anchors the soil, permitting new top-soil to form.

1.3 CLASSIFICATION OF GULLIES

Gullies are classified on three bases **size, cross-sectional shape and continuity** and each basis bears directly on the choice of control structure.

Basis	Classes	Field meaning
Size (depth | area)	Small (<1 m, <2 ha) | Medium (1–5 m, 2–20 ha) | Large (>5 m, >20 ha)	Sets the fall height, hence the structure type
Cross-section	U-shaped | V-shaped | Trapezoidal	U where top- & sub-soil erode alike (alluvium); V where sub-soil resists; trapezoidal where the bed is resistant
Continuity	Continuous (branching network) | Discontinuous (independent)	Continuous gullies need a system of structures; discontinuous ones can often be filled

1.4 DESIGN GRADING FOR STRUCTURE SELECTION (G-1 TO G-4)

For design purposes, gullies are graded by the fall to be handled — this one figure selects the structure:

Grade	Fall / depth	Recommended treatment
G-1	< 1 m fall	Temporary structures (brushwood, loose-rock, log check dams)
G-2	up to 3 m fall	Drop spillway
G-3	3–6 m fall (depth > 3 m)	Chute spillway
G-4	> 6 m fall / > 9 m deep, steep sides	Drop-inlet (pipe) spillway

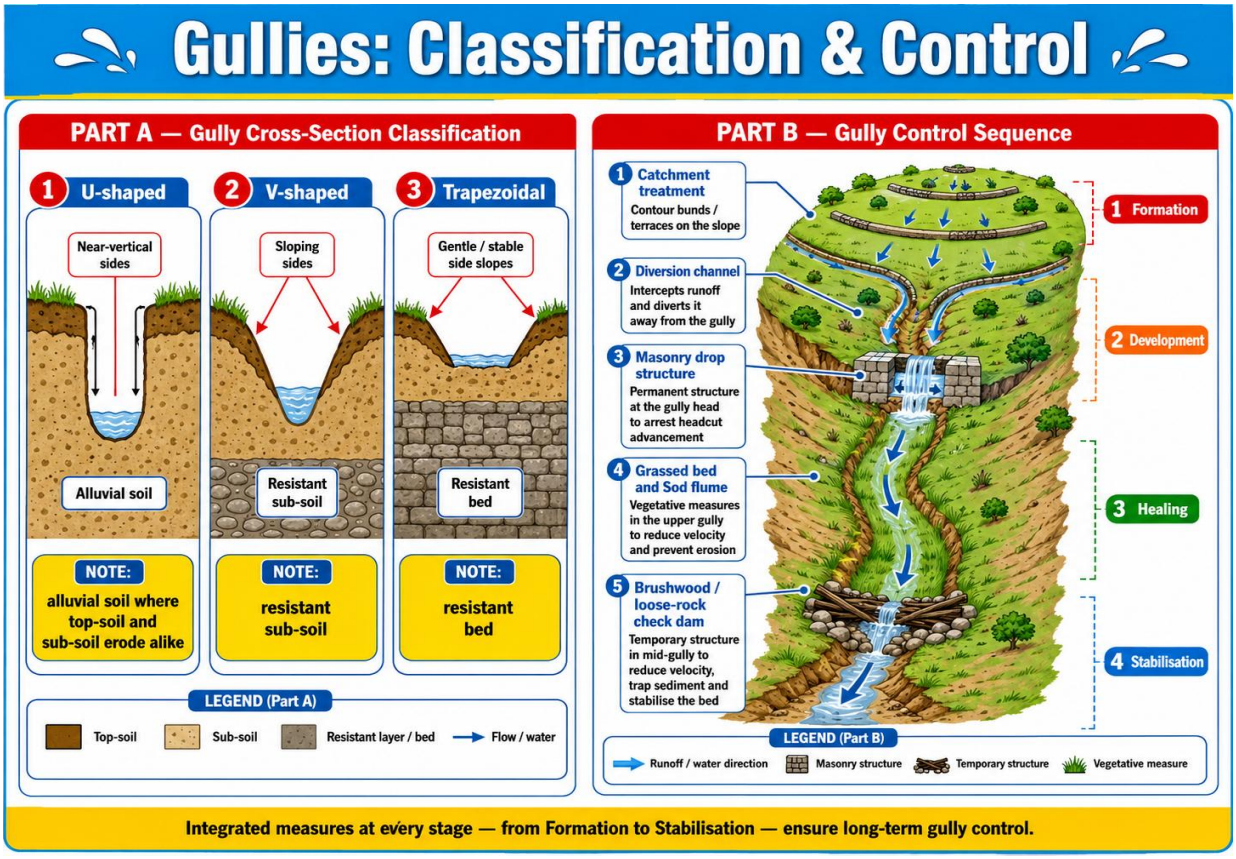
1.5 CLASSIFICATION OF SOIL-CONSERVATION STRUCTURES

- **By permanence :** temporary (life 3–8 yr, local materials) vs permanent (life 25–50 yr, masonry / RCC).
- **By nature of control :** biological / vegetative (living cover) vs engineering (built structures).
- **By function :** grade-stabilisation (drop, chute, drop-inlet spillways; check dams), water-storage (farm & percolation ponds), and diversion / retention (bunds, terraces, diversion drains).

When are permanent structures recommended? (OPSC)

- When the gully is active and deep (G-2 to G-4), so vegetative or temporary measures cannot hold it
- When the drainage area and peak runoff are large
- When a permanent grade-control point is needed to stop head-cutting
- When the benefit (protection of land and roads, water storage, reduced sediment to reservoirs) justifies the cost
- When the gully bed below the site is stable enough to found a masonry structure

© Hornbill Classes
+91 78802-71423 Hornbillclasses@gmail.com



Source — Soil & Water Conservation Engineering, L7 Gully Erosion, p.46–51, 58; Gully & Ravine Control Structures, L1, p.6–11; Soil & Water Conservation Structures, L13, p.119–124.

2. GULLY CONTROL — PRINCIPLES, BIOLOGICAL & TEMPORARY MEASURES

PREVIOUS YEAR QUESTIONS

- Explain the measures for controlling gully formation.*** [IFoS 2019 | P1/2(b) | 10M]
- Different methods of gully control; steps followed in design of gully-control structures.*** [IFoS 2017 | P1/4(d) | 10M]
- Temporary structures for gully control; suitability criteria for various check dams (with diagrams).*** [UK·PSC 2012 | Q1(ii) | 10M]
- Temporary gully-control measures.*** [OPSC·CSE 2020-21 | Q5(d)(ii) | 5M]

2.1 PRINCIPLES — CONTROL THE WATER FIRST, THE GULLY SECOND

A gully lives on the concentrated runoff that feeds it, so ***controlling the runoff is always the first step***. Measures follow a definite order of preference:

- **Retain runoff on the drainage area :** improve land use so that less runoff is generated: contour cultivation, strip cropping, bunding, terracing, afforestation of the catchment.
- **Divert runoff around the gullied area :** intercept the flow above the gully head with diversion drains or terraces and lead it at non-erosive velocity to a safe outlet.
- **Convey runoff safely through the gully :** only when retention and diversion are not feasible: establish vegetation in the gully and build grade-control structures at critical points.

2.2 CLASSIFICATION OF GULLY-CONTROL MEASURES

Control measures fall into two families, almost always used in combination:

Family	Examples	Role
Biological / vegetative	Anti-erosion crops; conversion to grassed waterway; sod flumes; sod-strip checks; low sodded earthfills; trees & shrubs on gullied land	Living cover dissipates raindrop and flow energy; suited to gentle slopes and small gullies
Engineering — temporary	Woven-wire, brush, loose-rock, plank / slab, log and boulder check dams	Cheap, local-material barriers; hold soil & moisture until vegetation establishes (life 3–8 yr)
Engineering — permanent	Drop, chute and drop-inlet spillways; permanent masonry check dams	Grade-control at critical points; life 25–50 yr (dealt with in §3–§8)

2.3 BIOLOGICAL MEASURES

- **Grassed waterway conversion :** small / medium gullies are shaped to a broad, flat section and seeded with grass so the runoff spreads and flows at non-erosive velocity.
- **Sod flume :** a grassed apron laid over an over-fall (head < 3 m, area < 10 ha; max slope 4:1; depth of flow < 30 cm) that prevents waterfall erosion at the gully head.
- **Sod-strip checks & low sodded earthfills :** strips of sod (≥ 30 cm wide, spaced 1.5–2 m) or small sod-faced earth fills (≤ 45 cm high, u/s 3:1, d/s 4:1) laid across small gullies.
- **Vegetative barriers, trees & shrubs :** close-planted stiff grasses (vetiver) or fenced tree planting (spacing 1×1 to 2×2 m) to stabilise severely gullied land.

2.4 TEMPORARY (ENGINEERING) CHECK DAMS

Temporary check dams are small barriers thrown across the gully bed using **locally available material**. Their job is to flatten the channel gradient, trap sediment and hold moisture until vegetation establishes; their life is **3–8 years**.

Common design criteria (all temporary checks). effective height about 30 cm (overall ≤ 75 cm) with adequate free-board; designed for a 5–10 year peak; spaced so the crest of one dam is at the bed level of the next upstream (spacing = effective height ÷ (original bed slope − stable bed slope), which reduces to height ÷ channel slope when the stable grade is taken as flat); a downstream apron / rip-rap to catch the falling nappe.

Check dam	Best suited to	Key feature
Woven-wire	Moderate slope (< 10%), small area, no boulders	Half-moon plan, open end u/s; wire on posts @1.2 m; apron 1.2 m
Brush	Small drainage area	Cheapest, least stable; centre kept low to pass flow over
Loose-rock	Small–medium area, stone available	Flat keyed stones in a 30-cm trench; centre low for spillway
Plank / slab	Larger area, timber available	Planks across gully; notch spillway; earth fill u/s, apron d/s
Log	Incipient / small gullies (< 100 m, < 2 ha)	Two rows of posts, logs packed between; rectangular notch
Boulder	Continuous gullies (≤ 20 ha)	Max 2 m high; d/s face 1:0.3; trapezoidal spillway; no stability test needed if standard dims used

© Hornbill Classes
+91 78802-71423 Hornbillclasses@gmail.com

⌘ *Notch of a wooden slab check dam*

Full question. Design the notch dimensions of a wooden slab dam to carry a peak flow of 0.6 m^3/s. The notch is rectangular; width of gully channel = 2.5 m.

Notch length L = gully width = **2.5 m = 250 cm**.

Weir formula (temporary check, SI, per L in cm): **$Q = 0.0171 \mid L \mid H^{1.5}$** with Q in litres/s.

$600 = 0.0171 \times 250 \times H^{1.5} \Rightarrow H^{1.5} = 140.35 \Rightarrow H =$ **27 cm**.

Add free-board ≈ 5 cm ⇒ total notch depth = **32 cm**.

Answer: notch 2.5 m long × 32 cm deep.

2.5 MEASURES FOR CONTROLLING GULLY FORMATION — MODEL ANSWER FRAME

- Treat the catchment (land-use, contour bunds, terraces) to cut peak runoff
- Divert surface water above the gully head
- Stabilize the gully by biological measures on gentle reaches and temporary check dams / permanent spillways on active reaches
- Re-vegetate the healed gully
- Close with the maxim that prevention — checking rills before they deepen — is far cheaper than cure

3. PERMANENT SOIL-CONSERVATION STRUCTURES — DESIGN FRAMEWORK

PREVIOUS YEAR QUESTIONS

- Discuss the design procedure of permanent soil-conservation structures.*** [IFoS 2018 | P1/3(d) | 10M]
- Different types of spillways used in gully control; compare their structural and design features. *** [IFoS 2019 | P1/3(c) | 10M]
- Main functions of permanent soil-conservation structures; when is a drop spillway required and how does it differ from a chute spillway?*** [UK·PSC 2021 | Q1(ii) | 10M]
- Conditions under which permanent gully-control structures are recommended (with diagrams). *** [OPSC·CSE 2018-19 | Q8(a) | 20M]
- Explain permanent gully-control structures with a neat sketch. *** [OPSC·CSE 2022-23 | Q15(a) | 8M]
- Main differences among drop, chute and drop-inlet spillways. *** [OPSC·CSE 2024-25 | Q9 (part)]

3.1 FUNCTIONS OF PERMANENT STRUCTURES

A permanent gully-control structure is built of masonry or RCC to last 25–50 years, and its entire purpose is to **provide safe passage to concentrated flow across a change of grade**. Its functions are to:

- halt the advance (head-cutting) of the over-fall at the gully head and fix a permanent grade-control point;
- lower the water abruptly or convey it down a steep reach without eroding the bed;
- dissipate the kinetic energy of the falling / rushing water within the structure so the downstream channel is protected;
- store water in the upstream reach and trap sediment, aiding re-vegetation of the gully.

3.2 COMMON COMPONENTS — INLET, CONDUIT, OUTLET

Every permanent spillway, whatever its type, shares the same three functional parts:

- **Inlet** — admits the flow (a weir / notch, or a box); it controls and steadies the discharge entering the structure.

- **Conduit / main body** — conveys the flow through the structure (an open rectangular channel in a chute, a closed pipe in a drop-inlet).
- **Outlet** — discharges the flow into the downstream channel at a safe velocity; it houses the energy-dissipating device (stilling basin / apron with a hydraulic jump).

3.3 SELECTION — THE FALL HEIGHT DECIDES THE STRUCTURE

Fall / head	Structure	Basis of choice
< 1 m	Temporary check dam	Small over-fall, vegetation-establishment only
up to 3 m	Drop spillway	Economical weir-and-apron structure for low drops
3–6 m	Chute spillway	Less material than a drop structure at higher drops; conveys large flows on steep faces
> 6 m (deep, steep-sided)	Drop-inlet pipe spillway	Uses temporary storage; least material for high heads; needs an earthen embankment

3.4 DESIGN PROCEDURE OF A PERMANENT STRUCTURE (IFOS 2018)

Design proceeds in two phases — **site investigation** then **engineering design**.

(a) ***Site investigation & selection.*** topographic (channel-profile) survey to fix a site of uniform cross-section and native grade; sediment survey; land-use and socio-economic appraisal (to justify benefit vs cost); and geologic investigation of the foundation.

(b) ***Hydrologic design.*** estimate the design **peak runoff rate** (Rational method, Q = CIA/360) for drop and chute spillways, and the **runoff volume / inflow hydrograph** (with flood routing) for the drop-inlet spillway. The return period is fixed from the structure's design life:

Structure	Design frequency (yr)
Storage / diversion dam (permanent spillway)	50–100
Earth-fill dam with natural spillway	25–50
Small permanent masonry gully-control structure	10–15
Terrace outlet & vegetated waterway	10

(c) ***Hydraulic design.*** fix the dimensions of inlet, conduit and outlet to pass the design flow and to dissipate its energy (weir length & head, apron / stilling-basin length, sill and wing-wall heights).

(d) ***Structural design.*** check stability of the section against **overturning, sliding, tension, compression (crushing) and piping** under hydrostatic, earth, uplift and self-weight forces; specify material and thickness (detailed in §4 for the drop spillway).

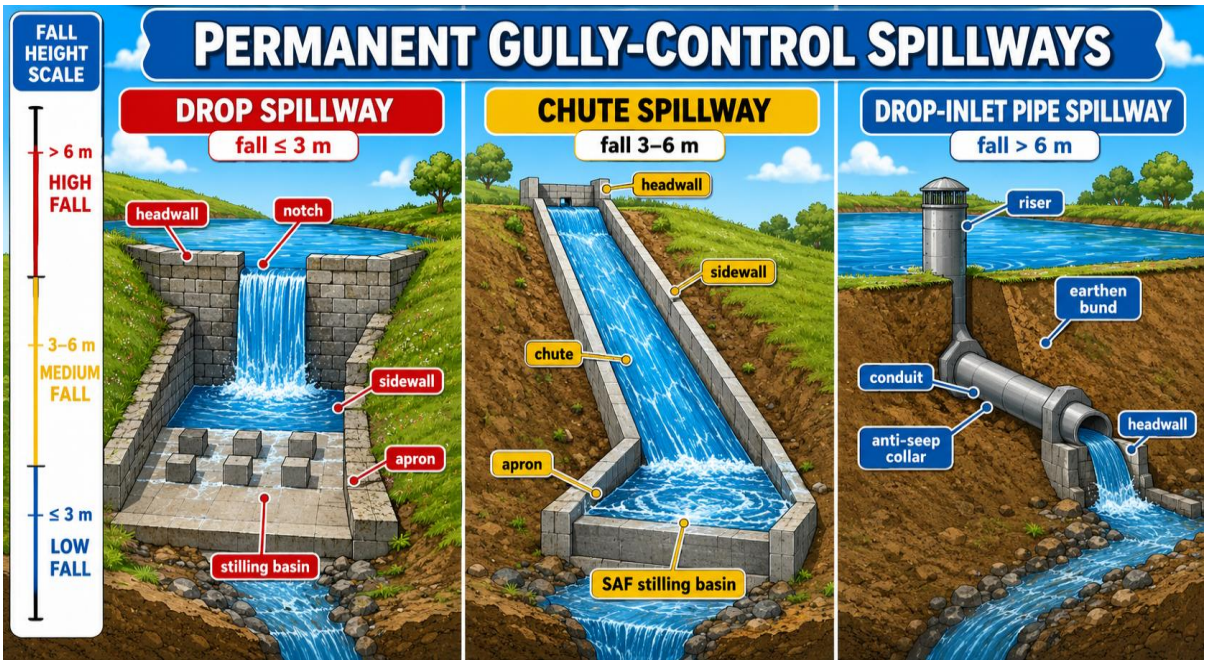
Two chief causes of failure — worth quoting in every answer — are **insufficient hydraulic capacity** and **inadequate energy dissipation**; the whole design guards against these two.

3.5 THE THREE PERMANENT SPILLWAYS COMPARED (IFOS 2019 | OPSC)

Feature	Drop spillway	Chute spillway	Drop-inlet (pipe) spillway
Head range	≤ 3 m	3–6 m	> 6 m
Inlet	Straight / box weir	Straight / box weir	Vertical riser (box / funnel)
Flow path	Free fall onto apron	Down a paved open channel	Weir → vertical → horizontal pipe
Energy	Hydraulic jump on apron	SAF stilling basin at	Impact / friction in pipe + outlet

© Hornbill Classes
+91 78802-71423 Hornbillclasses@gmail.com

dissipation		toe	
Storage used?	No	No (optional)	Yes — temporary storage reduces peak
Debris / clogging	Not a problem	Not a problem	Riser can clog
Relative cost	Low at small drops	Economical at 3–6 m	Least material at high heads
Design method	Rational (peak rate)	Rational (peak rate)	Flood routing (inflow–storage–outflow)



Source — Soil & Water Conservation Structures, L13–14 (design requirements & procedure), p.119–130; Soil & Water Conservation Engineering, L8 (PGCS), p.58–60.

4. DROP SPILLWAY — THEORY, DESIGN & STRUCTURAL STABILITY

PREVIOUS YEAR QUESTIONS

- Objectives of a drop spillway; advantages and limitations; procedure for its design.*** [IFoS 2021 | P1/3(c) | 20M]
- Design a drop spillway in a gully (width 5 m, area 58 ha, net drop 2 m; i=120 mm/h, T=25 yr, C=0.3, stone masonry). *** [IFoS 2019 | P1/3(c) | 10M]
- Determine the height of the wing wall of a drop structure (F=2.5 m, h=1.5 m, S=0.5 m). *** [IFoS 2023 | P1/3(c) | 15M]
- Adaptability and functions of a drop spillway. *** [IFoS 2020 | P1/1(a) | 8M]
- Size of each side of a square box inlet for a drop spillway (Q=3.2 cumec, fall 1.5 m, energy-head/fall ratio ≤ 0.6). *** [IFoS 2025 | P1/2(c)(ii) | 5M]
- Purpose of the structural components of a drop spillway (with sketch).*** [UK·PSC 2015 | Q1(iii) | 10M]
- Functions, advantages and limitations of a drop spillway; label a straight-inlet drop spillway.*** [UK·PSC 2012 | Q2(i) | 10M]

- Draw a drop spillway; label and describe the functions of its parts.*** [OPSC·Forest 2015-16 | Q3(a) | 10M]
- Differentiate a drop spillway from a drop-inlet pipe spillway.*** [OPSC·CSE 2018-19 | Q5(b)(ii) | 10M]

4.1 WHAT IT IS AND WHERE IT IS USED

A ***drop spillway*** (straight drop / straight-inlet drop structure) is a **weir structure**: the flow passes through a rectangular notch in the head-wall, falls freely onto a level apron (stilling basin) where a hydraulic jump dissipates its energy, and then passes tamely into the downstream channel. It is the commonest gully-control structure, used at the gully bed to fix a **grade-control point**; a series of them across the gully length breaks the flow, traps sediment and progressively fills the section.

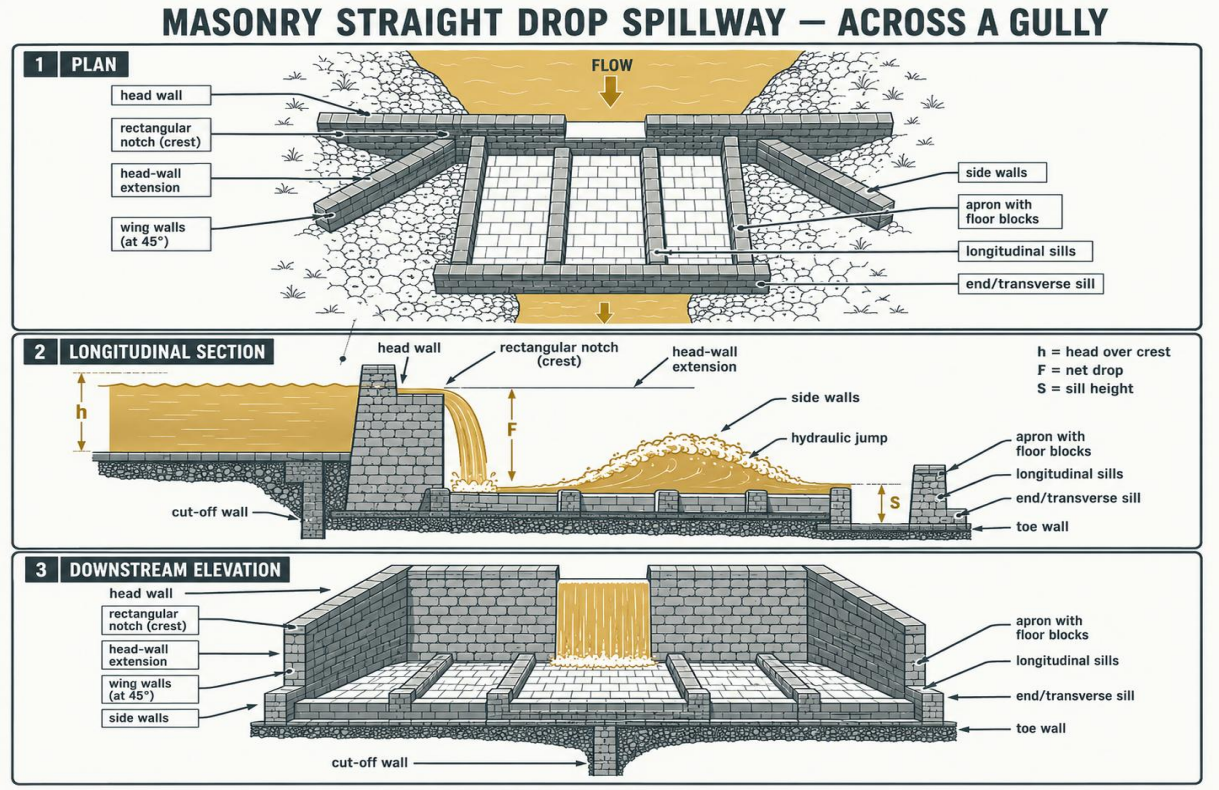
Adaptability (IFoS 2020). an efficient structure for **low drops, normally up to 3 m**, where no temporary storage is required. Below a discharge of ~3 m^3/s combined with drops above 3 m it becomes uneconomical and a chute or drop-inlet is preferred.

4.2 COMPONENTS AND THEIR FUNCTIONS (LABEL THESE IN THE SKETCH)

- **Head wall :** front wall across the gully carrying the rectangular notch (weir); admits and controls the flow.
- **Head-wall extension :** head wall carried into the gully banks; gives resistance against sliding and prevents piping and flow around the ends.
- **Wing walls :** at the rear, inclined ~45° to the gully sides; stop water flowing back into the space between the side wall and the bank and protect the banks.
- **Side walls :** run along the gully sides; confine the flow to the apron and prevent splashing over the banks.
- **Apron (stilling basin) :** level downstream floor that receives the falling sheet; roughened by blocks so a hydraulic jump forms and dissipates the kinetic energy.
- **Longitudinal sills :** run lengthwise on the apron; stabilise the apron (height ≈ h/4).
- **End sill (transverse sill) :** raised rear lip of the apron; raises the tail-water to hold the jump and stops water shooting straight into the channel.
- **Cut-off walls & toe wall :** buried keys under the structure; add frictional resistance against sliding, lengthen the creep path (anti-piping) and prevent undercutting of the apron.

Energy-dissipation logic (why the apron and end sill work). The falling sheet strikes the apron at super-critical velocity (Froude number $Fr = v/\sqrt{(g \cdot d)} > 1$). The end sill raises the tail-water and forces a hydraulic jump that converts the flow to sub-critical ($Fr < 1$), destroying most of its kinetic energy within the basin; the apron length and end-sill height are fixed so that the jump forms wholly on the apron, protecting the downstream channel from scour.+

© Hornbill Classes
+91 78802-71423 Hornbillclasses@gmail.com



4.3 USES, ADVANTAGES AND LIMITATIONS

Uses / objectives (IFoS 2021). grade stabilisation of gullies and waterways — providing a transition between a flat-graded waterway and the gully below, raising and stabilising the flow line for vegetative establishment; control of tail-water at a conduit / spillway outlet; low-head reservoir spillway; outlet for tile-drainage systems; and controlled release of irrigation water.

Advantages. very stable and rugged; the rectangular weir seldom clogs with debris; simple, standardisable and cheap to build; not undermined by rodents; low maintenance.

Limitations. use limited to drops ≤ 3 m; uneconomical where Q < 3 m^3/s but the drop exceeds 3 m; cannot exploit temporary storage to cut the peak; and it cannot be built where the gully grade below the site is unstable.

4.4 HYDRAULIC DESIGN

Step 1 : peak discharge (hydrologic). by the ***Rational method***,

Q = C·I·A / 360

Q : in m^3/s,

C : runoff coefficient,

I : mm/h for duration = time of concentration at the design return period, **A** in ha).

Step 2 : the weir (inlet). ***the notch is a rectangular weir***,

$Q = 1.71 \mid L \mid h^{1.5}$

(weir coefficient **C** = 1.71; some texts adopt 1.72 — either is accepted if stated). Fix

L - (often = gully width) and solve for the head **h**. Two checks govern economy and scour:

- **h / F ≤ 0.5** (never > 0.75) — limits scour on the apron; and
- **L / h ≥ 2** for a well-proportioned rectangular weir. A free-board of 15–30 cm is added to ***h*** for the side-wall height.

- Why it matters: h/F controls how much energy the falling jet carries onto the apron (lower ratio = safer against scour), while L/h ensures the crest is long enough relative to head for stable, uniform overflow.

Step 3 — component dimensions (F = net drop, h = head, S = sill).

Component	Design relation
Height of transverse (end) sill, S	S = h / 3
Height of longitudinal / end sill, HL	HL = h / 4
Height of head wall, HB	HB = F + S
Height of head-wall extension, HE	HE = F + S + h
Min. length of head-wall extension, E	E = greater of (3h + 0.6) and 1.5 F
Height of wing/side wall at junction, J	J = greater of 2h and the drop-based value
Depth of cut-off & toe wall, C = T	C = 1.65 (HL + 0.4F + 0.75) / 4 (USDA)

⌘ *Full drop-spillway design (IFoS 2024)*

Full question. Design a drop spillway across a gully of width 5 m, drainage area 58 ha, net drop 2 m. Rainfall intensity for duration = time of concentration at 25-yr return period = 120 mm/h; runoff coefficient 0.3; stone masonry.

Solution : 1) Peak discharge:

$Q = C \cdot I \cdot A/360$ = 0.3 × 120 × 58 / 360 = **5.8 m³/s**.

2) Head over crest (L = gully width = 5 m):

$Q = 1.71 \mid L \mid h1.5$

$h = [Q/(1.71\ L)](2/3)$ = $[5.8/(1.71\times5)]^{(2/3)}$ = **0.77 m**.

Checks: h/F = 0.77/2 = 0.39 (< 0.5 ✓);

L/h = 5/0.77 = 6.5 (> 2 ✓).

3) Components:

Height of transverse (end) sill $S = h/3$ = **0.26 m**;

Height of longitudinal / end sill $HL = h/4$ = **0.19 m**;

Height of head wall $HB = F+S$ = **2.26 m**;

Height of head-wall extension $HE = F+S+h$ = **3.03 m.**

Head-wall extension **E = greater of (3×0.77+0.6 = 2.91) and (1.5×2 = 3.0) = 3.0 m.**

Cut-off / toe wall $C = T$ **= 1.65(0.19 + 0.4×2 + 0.75)/4 = 0.72 m.**

Answer: *crest 5 m × head 0.77 m; sill 0.26 m; head wall 2.26 m; extension 3.0 m long, 3.03 m high; cut-off 0.72 m. Add 0.15–0.30 m free-board to the side walls; verify structural stability (§4.5).*

⌘ *Height of the wing wall (IFoS 2023)*

Full question. Determine the height of the wing wall of a drop structure: net drop from top of transverse sill to crest F = 2.50 m; head over crest h = 1.50 m; height of transverse sill S = 0.50 m.

The wing wall rises with the head wall from the apron to the top water line. Its full height at the junction with the head wall equals the height of the head-wall extension:

H(wing) = $F + S + h$ = 2.50 + 0.50 + 1.50 = **4.50 m**.

Related heights:

head wall HB = $F + S$ = **3.00 m;**

the junction check J = $2h$ = **3.0 m is smaller,**

so the full height 4.5 m governs the wing wall, which then slopes down to the apron at 45°.

© Hornbill Classes
+91 78802-71423 Hornbillclasses@gmail.com

⌘ *Square box inlet size (IFoS 2025)*

Full question. Determine the size of each side of a square box inlet for a drop spillway to handle a peak flow of 3.2 cumecs over a fall of 1.5 m, if the energy-head-to-fall ratio is not to exceed 0.6 at any time.

Solution : Limiting head:

$he/F \le 0.6 \Rightarrow he = 0.6 \times 1.5 =$ **0.9 m** (use this maximum, giving the smallest hence economical —box).

Box-inlet weir (flow enters over the upstream end + two sides = 3 sides),

$$Q = 1.71 \mid L \mid he^{1.5}$$

with crest length

$L = 3a$ (a = *side*):

$3.2 = 1.71 \times (3a) \times 0.9^{1.5}$

$3.2 = 1.71 \times 3a \times 0.854$

$a = 3.2 / 4.38 =$ **0.73 m (say 0.75 m each side)**.

Therefore,

"Size of square box inlet ≈ 0.73 m ×0.73 m

For field construction, adopt:

0.75 X 0.75 m

(***Assumptions:*** *weir coefficient 1.71; three-sided inflow over the square box; downstream face is the outlet. If all four sides are taken as effective,* $L = 4a$ *and* $a \approx 0.55$ *m — state the assumption used.*)

4.5 STRUCTURAL DESIGN & STABILITY

The section must be safe against **overturning, sliding, tension, compression (crushing) and piping**, under hydrostatic water pressure, active earth pressure of the fill, uplift on the base and the self-weight of the masonry. The worst case is **'soil filled to crest with water flowing over'**.

∑ DERIVATION — *Stability of the drop-spillway head wall (first principles)*

Set-up. *Take unit length of wall.*

Let ΣV = *net downward force (self-weight W minus uplift U),*

ΣH = *horizontal thrust (water pressure* P_w + *soil pressure* P_s*),*

acting at height $\bar{y}$ *above the base of width b;*

e = *eccentricity of the resultant from the base centroid.*

① Overturning. Restoring moment

ΣRM = about the toe from **W**;

overturning moment ΣOM = from P_w, P_s and U.

Factor of safety F.S.(o) = ΣRM / ΣOM ; required ≥ 1.5 (masonry), ≥ 1.2 (concrete).

② Sliding. Resistance = $f \cdot \Sigma V + C \cdot A$ ($f = \tan\varphi$, C = *cohesion*, A = *base area*).

F.S.(s) = (f·ΣV + C·A) / ΣH ≥ 1.5 ; for low structures require f·ΣV ≥ 1.5 ΣH.

③ No tension (middle-third). Base stress **σ = (ΣV/b)(1 ± 6e/b). For $\sigma_{min} \ge 0$, put $1 - 6e/b \ge 0$**

⇒ e ≤ b/6 :

the resultant must cut the base within the middle third. (Full treatment in §13.)

④ ***Piping.*** Weighted-creep ratio

$Cw = (\Sigma Lv + \Sigma Lh/3) / H$

must exceed the safe value for the soil (*e.g.* 2.3 firm clay, 6.5 clean sand); lengthen the cut-off if not met.

5. CHUTE SPILLWAY & SAF STILLING BASIN

PREVIOUS YEAR QUESTIONS

- Discuss the functions, limitations and design features of chute spillways.*** [IFoS 2017 | P1/3(c) | 10M]
- Adaptability and functions of a chute spillway.*** [IFoS 2020 | P1/1(a) | 8M]
- Chute spillway vs drop spillway (short note). *** [OPSC·CSE 2015-16 | Q7(b)(ii) | 10M]

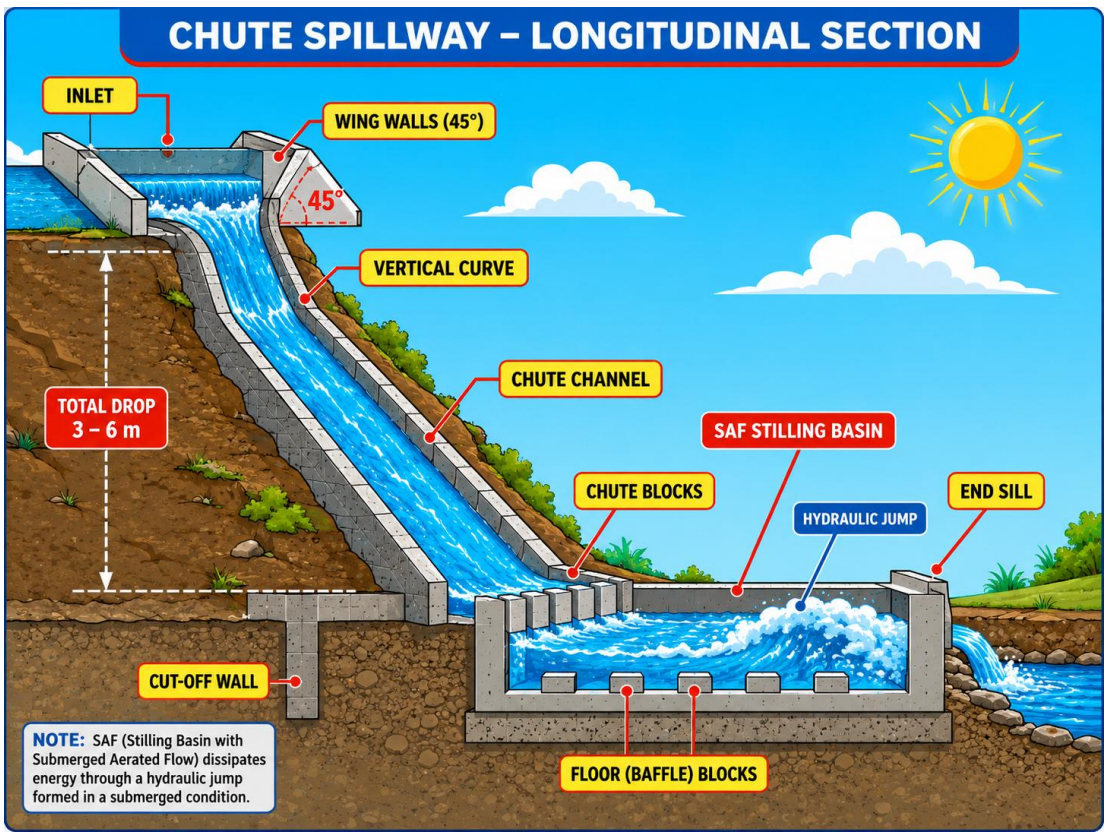
5.1 WHAT IT IS, ADAPTABILITY & FUNCTIONS

A ***chute (trough / open-channel) spillway*** carries the flow from the gully head to the bed down a **paved open channel laid on the steep face**. It has an inlet, a vertical curve, a steep sloped channel and an outlet; most of the drop occurs in the channel and the flow is at **super-critical velocity**. It is used for **drops of about 3–6 m** — beyond the economic reach of a drop spillway and is the choice when a large runoff volume must be conveyed and no temporary storage is available.

Functions. control the gully head; convey upstream runoff into the gully without erosion; act as a flood / water-conservation and sediment-collection structure; control the gradient of natural or artificial channels. Its capacity is not reduced by sedimentation at the outlet.

5.2 COMPONENTS

- **Inlet :** straight, box or side-channel type; a box inlet is used when a straight inlet cannot pass the flow at the available drop. The inlet section usually controls the capacity.
- **Channel (conduit) :** rectangular / trapezoidal paved chute, designed by Manning's equation; the vertical curve guides flow onto the steep bed without separation.
- **Outlet (energy dissipator) :** dissipates energy by a hydraulic jump, usually in an SAF (Saint Anthony Falls) stilling basin; straight-apron, cantilever or baffle outlets, or a flip bucket at large drops, are also used.



© Hornbill Classes
+91 78802-71423
Hornbillclasses@gmail.com

5.3 LIMITATIONS (IFOS 2017)

- danger of undermining by rodents — extra precautions needed;
- seepage can weaken the foundation in poorly-drained sites;
- the site and any earth fill must be thoroughly compacted — extra time and cost.
- the high super-critical velocity demands a strong, well-founded lining, and energy dissipation at the toe is critical.

5.4 DESIGN FEATURES

Inlet weir:

$Q = 1.71\ L\ h^{1.5}$

fixes the crest length.

Channel: sized by Manning's to carry Q super-critically

$V = (1/n)R^{(2/3)}S^{(1/2)}$

Outlet: a hydraulic jump converts the super-critical flow to sub-critical; the sequent (after-jump) depth is

$d_2 = (d_1/2)\cdot[\sqrt{(1 + 8\ Fr_1^2)} - 1]$

Froude number $Fr_1 = V_1 / \sqrt{(g\ d_1)}$

$Fr_1 = 1 \Rightarrow$ flow is at critical depth (unstable, avoided in design);

$Fr_1 < 1 \Rightarrow$ flow is sub-critical (tranquil) — no jump forms, so no stilling basin is needed.

$Fr_1 > 1 \Rightarrow$ incoming flow is super-critical (shooting) → a hydraulic jump will form.

SAF (Saint Anthony Falls) stilling basin (Blaisdell).

valid for $Fr_1 = 1.7–17$;

shortens the basin by ~80% using chute blocks, floor (baffle) blocks and an end sill.

Key relations: basin length $L_B = 4.5\ d_2 / Fr_1\text{^}0.76$;

block width & spacing = $0.75\ d_1$;

end-sill height = $0.07\ d_2$;

side-wall free-board above tail-water; wing walls at 45°, top sloped 1:1.

⌘ *Hydraulic jump at a chute outlet (SWC worked type)*

Full question. A hydraulic jump forms at the downstream end of a chute spillway carrying a flow velocity of 6 m/s; the depth of flow before the jump is 0.4 m. Will a jump occur, and if so what is the depth after the jump?

Froude number $Fr_1 = V_1/\sqrt{(g\ d_1)}$

$= 6/\sqrt{(9.81\times0.4)} = 6/1.981 = 3.03$.

$Fr_1 > 1 \Rightarrow$ incoming flow is super-critical (shooting) → a hydraulic jump will form.

Sequent depth $d_2 = (d_1/2)\cdot[\sqrt{(1 + 8\ Fr_1^2)} - 1]$

$d_2 = (0.4/2)[\sqrt{(1+8\times3.03^2)} - 1] = 0.2[\sqrt{74.4} - 1] = 0.2(8.63–1) =$ **1.53 m**.

The basin floor is set to hold this jump (SAF basin, Fr_1 within 1.7–17).

6. DROP-INLET (PIPE) SPILLWAY

PREVIOUS YEAR QUESTIONS

- With a neat sketch, explain the working of a drop-inlet spillway; under what situation is it preferred?*** [IFoS 2016 | P1/2(a) | 10M]
- A drop-inlet pipe spillway for 3 m³/s and 4 m head; pipe length 10 m; Ke=0.04, Kc=0.025. Find the pipe cross-sectional area.*** [IFoS 2021 | P1/2(b)(ii) | 10M]
- Differentiate a drop spillway from a drop-inlet pipe spillway; conditions for each.*** [OPSC·CSE 2018-19 | Q5(b)(ii) | 10M]

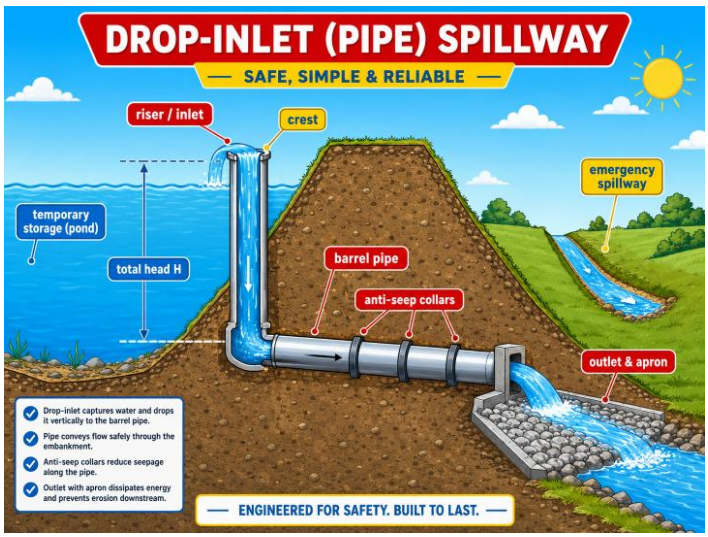
6.1 WORKING & WHEN IT IS PREFERRED

A ***drop-inlet (shaft / pipe) spillway*** carries the flow through or under an earthen embankment: water enters a **vertical riser** (box or funnel — the funnel form is the *morning-glory*), drops down it and passes through a **horizontal conduit** to a protected outlet downstream. The embankment ponds the runoff, so the structure **uses temporary storage** to reduce the outflow peak (outflow ≠ inflow).

Preferred when (IFoS 2016). the drop is high (> 6 m) and the gully deep with steep sides, where drop and chute structures are impractical; where temporary storage upstream is available to cut the peak; and as the principal spillway of farm ponds and small reservoirs, or a road-culvert inlet.

6.2 COMPONENTS & FLOW CONTROL

- **Riser / inlet :** box, catch-pit or funnel; flow first behaves as a weir over the riser rim.
- **Conduit :** as the head builds, control shifts to orifice / full-pipe flow; slope governs whether the pipe runs full.
- **Anti-seep collars :** increase the seepage (creep) length by ≥ 15% to prevent piping along the pipe.
- **Emergency spillway :** a grassed / pitched channel that passes flows beyond the design storm (25-yr) to save the embankment from overtopping.



6.3 HYDRAULIC RELATIONS

Weir control (low head):

$$Q = C \cdot L_r \cdot H^{1.5}$$

over the riser rim (L_r = riser perimeter).

Full-pipe (submerged) control:

$$Q = a \cdot \sqrt{[\, 2gH \,/\, (1 + K_e + K_c \cdot L)\,]}$$

where

a = pipe area,

H = total head,

K_e = entrance-loss coeff.,

K_c = friction-loss coeff.,

© Hornbill Classes
+91 78802-71423 Hornbillclasses@gmail.com

L = pipe length; the '1' is the exit velocity head.

⌘ *Pipe cross-sectional area (IFoS 2021)*

Full question. A drop-inlet pipe spillway is designed for a 3 m^3/s peak flow and 4 m total head. The pipe length is 10 m; entrance and friction loss coefficients are 0.04 and 0.025 respectively. Calculate the cross-sectional area of the pipe.

Given:

- ***Peak discharge*, $Q = 3\ m^3/s$**
- ***Total head*, $H = 4\ m$**
- ***Pipe length*, $L = 10\ m$**
- ***Entrance-loss coefficient*, $K_e = 0.04$**
- ***Friction-loss coefficient*, $K_c = 0.025$**

Velocity (full-pipe flow): $V = \sqrt{[2gH / (1 + K_e + K_c \cdot L)]}$

$= \sqrt{[2\times9.81\times4 / (1 + 0.04 + 0.025\times10)]}$

$= \sqrt{[78.48 / 1.29]} = \sqrt{60.84} = 7.80\ m/s.$

Area $a = Q / V = 3 / 7.80 =$ **$0.385\ m^2$**

diameter $d = \sqrt{(4a/\pi)} = 0.70\ m;$

adopt a 0.70–0.75 m pipe).

6.4 DROP SPILLWAY VS DROP-INLET PIPE SPILLWAY (OPSC 2018-19)

Basis	Drop spillway	Drop-inlet pipe spillway
Head	≤ 3 m	> 6 m
Flow path	Weir → free fall → apron	Riser → vertical drop → horizontal pipe
Storage	None (outflow = inflow)	Temporary storage; outflow < inflow
Embankment	Not required	Earthen embankment essential
Debris	Rarely clogs	Riser may clog
Material at high head	Uneconomical	Least material; economical
Design basis	Rational method (peak rate)	Flood routing (inflow–storage–outflow)

7. TRICKLE & FLOOD SPILLWAYS FOR EARTH DAMS

PREVIOUS YEAR QUESTIONS

Discuss the requirements and essential features of trickle spillway and flood spillway in an earth dam.***

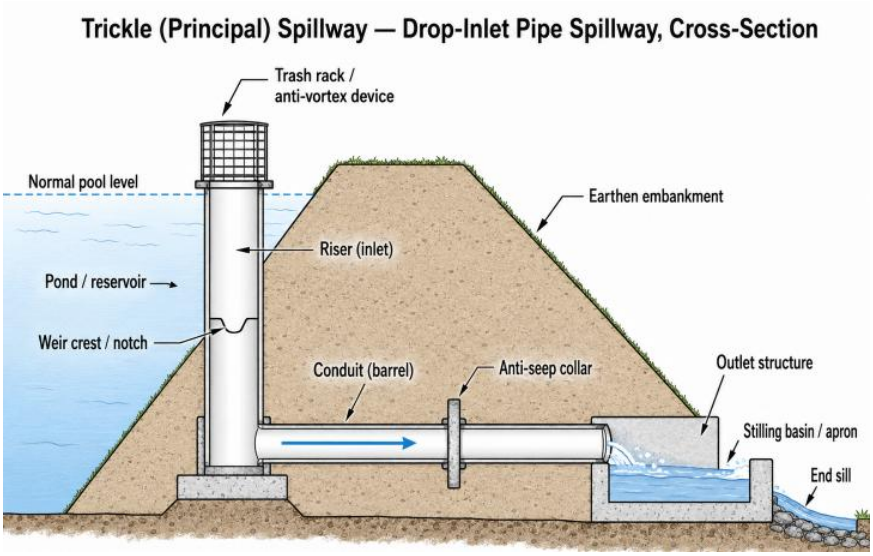
[IFoS 2025 | P1/1(d) | 8M]

An earth dam (or farm-pond embankment) is protected by **two spillways working together**: a ***trickle (principal) spillway*** that handles the ordinary, frequent flows and a ***flood (emergency) spillway*** that safely passes the rare large flood. Because an earth embankment **must never be overtopped**, these two act as its safety valves.

7.1 TRICKLE (PRINCIPAL / MECHANICAL) SPILLWAY

Usually a **pipe with a vertical riser (a drop-inlet)** set at the normal (full-supply) pool level and led through the embankment to a protected outlet.

Requirements & essential features.



- crest at the normal storage level, so it carries away small continuous / base flows and holds the pond at its design level;
- designed to pass the more frequent design flood (routed through storage), keeping the emergency spillway dry most of the time;
- fitted with anti-seep collars and a watertight, non-erodible (RCC / metal) conduit taken below the saturation line;
- an energy dissipator / apron at the outlet; it lowers the pond after a storm to restore flood-storage before the next event.

7.2 FLOOD (EMERGENCY / BY-WASH) SPILLWAY

Usually a **grassed or paved open channel (a saddle / by-wash)** cut into firm ground at one flank, with its crest a little above the normal pool.

Requirements & essential features.

- crest above the trickle-spillway level, so it operates only when a large flood exceeds the principal spillway's capacity;
- capacity to pass the design (e.g. 25-yr or higher) peak so the embankment is not overtopped, with adequate free-board above the maximum flood level;
- located away from the embankment (in a flank / natural saddle), founded on firm ground and protected with grass or stone pitching against scour;
- a gentle, non-erosive grade returning the flow to the natural channel well downstream of the toe.

EXAM TIP — *terminology*
In Indian soil-conservation practice the **trickle spillway = principal / mechanical (pipe) spillway** and the **flood spillway = emergency / by-wash spillway**. State this equivalence at the start of the answer, then give requirements + features for each and a small labelled sketch.

Source — Soil & Water Conservation Structures, L20 (principal & emergency spillways, anti-seep), p.164–166; Reservoir & Farm-Pond Design, L4 (embankment spillways); trickle/flood ≡ principal/emergency spillway — USDA-NRCS pond standards (web: NRCS Pond Code 378; damsafety.org).

8. CHECK DAMS — PLANNING & DESIGN

PREVIOUS YEAR QUESTIONS

- What is a check dam? Write the uses of check dams. Explain the planning and design procedure of check dams.***

[IFoS 2022 | P1/3(a) | 15M]

© Hornbill Classes
+91 78802-71423 Hornbillclasses@gmail.com

Suitability criteria for designing various types of check dams (with diagrams). ***
[UK·PSC 2012 | Q1(ii) | 10M]

8.1 WHAT & WHY

A ***check dam*** is a small barrier built across a gully / channel to **reduce the bed gradient**, and hence the velocity and erosive power of runoff, while trapping sediment and holding moisture behind it. It may be **temporary** (brushwood, loose-rock, log — life 3–8 yr) or **permanent** (masonry / the drop, chute and drop-inlet spillways of §4–§6).

8.2 USES

- arrest channel-bed and head-cut erosion by flattening the gully grade;
- trap sediment and let the gully silt up to a stable, cultivable / vegetated grade;
- retain moisture and recharge groundwater — keeping the surrounding soil wet after the monsoon;
- reduce sediment load to downstream reservoirs and moderate small floods.

8.3 PLANNING & DESIGN PROCEDURE

- **Survey & spacing :** the key planning rule is that the crest of one dam is at the bed (toe) level of the next dam upstream, so the series eliminates the gully grade. Spacing = effective height ÷ (original bed slope − stable bed slope), taken in practice as ***HI = effective height : channel slope*** steeper gullies need closer dams.
- **Hydrologic design :** size the spillway / notch for the peak runoff of a 5–10-yr storm (temporary) or 25–50-yr storm (permanent), by the Rational method.
- **Hydraulic design :** fix the notch (weir) length and depth to pass the peak with free-board; provide a downstream apron / rip-rap to catch the falling nappe and dissipate energy.
- **Structural design :** key the dam into the bed and abutments; check stability against overturning, sliding and piping for permanent (masonry) dams; effective height of temporary checks ≤ ~0.75 m with ≥ 15 cm free-board.
- **Foundation & keying :** trench the base and carry the ends into the banks up to crest level to stop outflanking and undermining.

8.4 SUITABILITY OF THE COMMON TYPES (UK·PSC 2012)

Type	Suitable where	Limit
Brushwood	small drainage area, brush available	runoff < 0.5–1 m^3/s; least stable
Loose-rock / gabion	stones available, small–medium area	effective height ~0.6–1 m
Log / plank	timber available, larger area	incipient / small gullies < 2 ha
Masonry (permanent)	active deep gullies, large area, benefit justifies cost	design life 25–50 yr

9. FARM PONDS — TYPES, SITE SELECTION, DESIGN & CAPACITY

PREVIOUS YEAR QUESTIONS

Utility of farm ponds; types by source of water and location; criteria for site selection.***

[IFoS 2018 | P1/4(c) | 10M]

- Different types of farm ponds and their essential design requirements. *** [IFoS 2017 | P1/3(d) | 10M]
- Calculate the capacity of a pond from the area enclosed by different contours. ***

[IFoS 2024 | P1/3(b) | 15M]

- Volume of water in a trapezoidal pond at 100% and 50% depth (bottom 21×45 m, depth 3 m, side slope 2:1). ***

[IFoS 2020 | P1/2(b) | 15M]

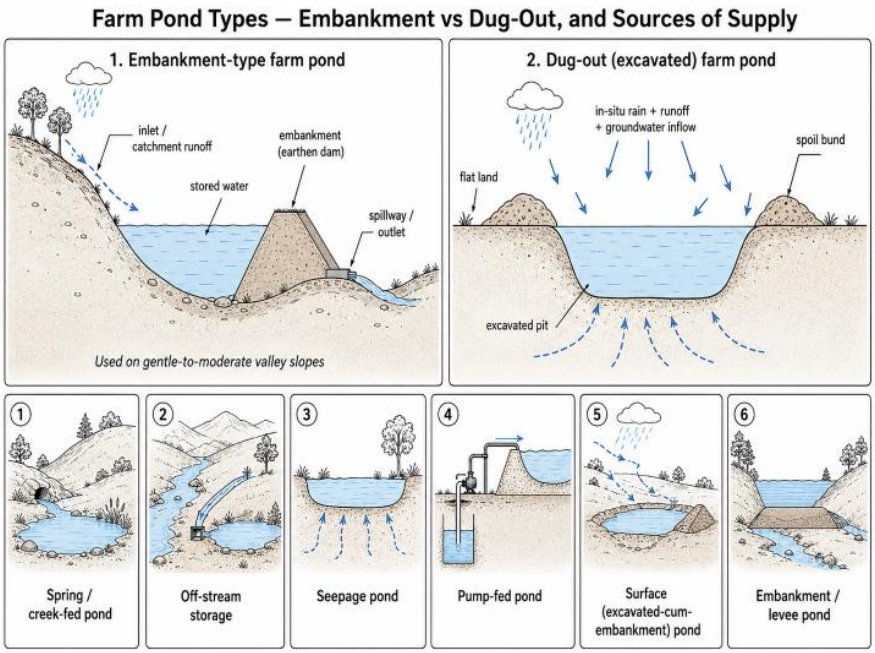
- Volume of excavation for a dug-out farm pond (avg depth 5 m, bottom 15×25 m, side slope 2:1). ***

[IFoS 2019 | P1/3(d) | 10M]

- Components of a farm pond; design criteria of a farm pond. *** [OPSC·Forest 2023-24 | Q2(b) | 20M]
- Capacity of a farm pond from contour areas (interval 1 m). *** [OPSC·CSE 2020-21 | Q5(b)(ii) | 12M]

9.1 UTILITY OF FARM PONDS

A ***farm pond*** is a small water-harvesting reservoir that stores monsoon runoff for **supplemental / life-saving irrigation**, pre-sowing irrigation of rabi crops, livestock and domestic supply, fish culture and groundwater recharge. It buffers the farmer against rainfall variability and is central to rainfed watershed development (rainfall > 500 mm).



9.2 TYPES OF FARM PONDS

By construction & topography ponds are **embankment type** (an earthen dam across a water-course, for gentle-to-moderate valley slopes) or **dug-out / excavated type** (dug into flat land, spoil forming the bund).

By source of water & location (IFoS 2018):

Type	Fed by / location
Dug-out (excavated)	in-situ rain + surface runoff + groundwater; flat land
Surface (excavated-cum-embankment)	surface runoff into a natural depression
Spring / creek-fed	a spring or creek at a foot-hill
Off-stream storage (diversion / barrage)	water diverted from a seasonal stream
Seepage pond	seepage from the water table
Pump-fed	pumped from a well / canal / lake to a higher pond
Embankment / levee	impounded behind an embankment across the course

9.3 SITE-SELECTION CRITERIA (DUG-OUT POND)

- **Soil :** deep, fine-textured, low-permeability soil that holds water; avoid stony / boulder ground and highly permeable sands (unless lined).

© Hornbill Classes
+91 78802-71423 Hornbillclasses@gmail.com

- **Topography :** a site giving the largest storage for the least excavation (high storage-to-excavation ratio); pond located to intercept maximum runoff.
- **Catchment :** adequate catchment-to-cultivable-area ratio to fill the pond in an average year without excessive silt.
- **Others :** proximity to the command area, safe inlet / outlet sites, and land not prone to heavy flood damage.

9.4 COMPONENTS & DESIGN REQUIREMENTS

- **Embankment / dyke :** with top width $T \approx H/5 + 1.5\ (m)$ alternatively $T = 1.67\cdot\sqrt{H}$, the larger value governing, practical ***minimum*** ≈ *1–2.5 m — u/s slope 3:1, d/s 2.5:1, plus 15% free-board and 5%* settlement allowance.
- **Mechanical (inlet) :** stone-pitched / grassed inlet channel bringing runoff in at non-erosive velocity.
- **Spillways :** a principal (trickle) spillway at full-supply level and an emergency (waste-weir / flood) spillway above it — see §7 & §11.
- **Lining (dug-out) :** LDPE / HDPE film, brick or cement to cut seepage (can be 60% of storage); side slopes per soil (clay 1:1–2:1, sandy 3:1); ideal depth 3–3.5 m.

9.5 CAPACITY OF A POND

From a contour survey, the volume between successive contours (interval h, areas A_1, A_2 …) is found by:

Trapezoidal: $V = \Sigma\ (h/2)(A_i + A_{i+1})$

Prismoidal (Simpson): $V = (h/3)[A_0 + 4(odd) + 2(even) + A_n]$.

For a regular dug-out pond the prismoidal (three-level) formula is used: $V = (D/6)(A_top + 4\ A_mid + A_bottom)$.

⌘ *Capacity from contour areas (IFoS 2024 | OPSC method)*

Full question. Calculate the pond capacity from the contour areas (contour interval 1 m). [Illustrative data: contours 100–104 m enclose 500, 900, 1500, 2200, 3000 m².]

Given:

- ***Contour interval, h = 1 m***
- ***Enclosed areas at successive contours (100–104 m): 500, 900, 1500, 2200, 3000 m²***

Trapezoidal: $V = \Sigma\ (h/2)(A_i + A_{i+1})$

Trapezoidal: $V = (1/2)\ [(500+900) + (900+1500) + (1500+2200) + (2200+3000)]$

$= 0.5[1400+2400+3700+5200] = 0.5\times12700 =$ **6350 m³**.

Prismoidal (Simpson, 5 contours):

Prismoidal (Simpson): $V = (h/3)[A_0 + 4(odd) + 2(even) + A_n]$.

$V = (1/3)\ [500 + 4(900+2200) + 2(1500) + 3000]$

$= (1/3)\ [500+12400+3000+3000] =$ **6300 m³** (more accurate).

Apply the same summation to the area–contour table given in the question.

⌘ *Trapezoidal pond volume at 100% and 50% depth (IFoS 2020)*

Full question. Trapezoidal pond: depth 3.0 m, side slope 2:1 (H:V), bottom 21 m × 45 m. Find the volume when filled to (i) 100% and (ii) 50% of depth.

Given:

- ***Depth, D = 3.0 m***

- ***Side slope = 2:1 (H:V)***
- ***Bottom dimensions = 21 m × 45 m***
- ***Find: volume at (i) 100% and (ii) 50% of depth***

Bottom area: $A_b = 21 \times 45 = 945\ m^2$. Each side spreads 2×(depth) horizontally.

Full (3 m): A_top = (21+12) (45+12) = 33×57=1881;

A_mid(1.5 m) = (27) (51) = 1377.

$V = (D/6)\,(A_b + 4A_mid + A_top)$

= (3/6) (945+4×1377+1881) = 4167 m^3 (avg-end area gives 4239 m^3).

(ii) Half-depth (1.5 m): A@1.5=1377; A_mid (0.75) = 24×48=1152.

V = (1.5/6) (945+4×1152+1377) = **1732 m^3**.

⌘ *Excavation volume of a dug-out pond (IFoS 2019)*

Full question. Compute the volume of excavation: average depth 5.0 m, bottom width 15 m, bottom length 25 m, side slope 2:1.

Given:

- ***Average depth, D = 5.0 m***
- ***Bottom width = 15 m***
- ***Bottom length = 25 m***
- ***Side slope = 2:1 (H:V)***

A_bottom = 15×25 = 375 m^2;

horizontal spread = 2×5 = 10 m each side.

A_top = (15+20) (25+20) = 35×45 = 1575 m^2;

$A_mid\ (2.5\ m)$ = 25×35 = 875 m^2.

$V = (D/6)\,(A_top + 4A_mid + A_bottom)$ = (5/6) (1575 + 3500 + 375) = **4542 m^3**.

10. PERCOLATION PONDS & PERCOLATION TANKS

PREVIOUS YEAR QUESTIONS

- Discuss the purpose, advantages and limitations of a percolation tank.*** [IFoS 2023 | P1/1(c) | 8M]
- Uses of a percolation pond (with farm-pond design steps).*** [OPSC-CSE 2022-23 | Q16(a) | 8M]

A ***percolation tank / pond*** is an artificially created surface-water body usually a small earthen bund across a minor (2nd–3rd order) stream — built **not to store water for use but to impound monsoon runoff so that it seeps into the ground and recharges the aquifer**. Its bed lies over permeable or fractured / weathered strata, and it is normally designed to empty by percolation within a few months of the monsoon.

10.1 PURPOSE

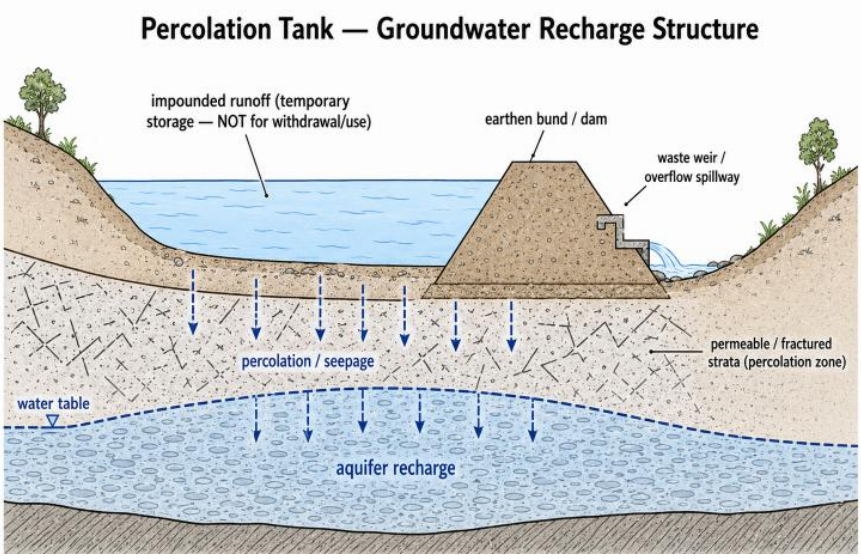
- augment groundwater recharge and revive down-gradient wells and springs;
- even out water availability — store the monsoon surplus underground for the dry season;
- reduce runoff, soil erosion and downstream flooding, and aid soil-moisture conservation.

10.2 SITE & DESIGN ESSENTIALS

- located on permeable soil / fractured rock on a small tributary, above a good aquifer;

© Hornbill Classes
+91 78802-71423 Hornbillclasses@gmail.com

- capacity governed by the percolation capacity of the bed strata, not the catchment yield — if percolation is slow the water is merely lost to evaporation;
- designed so the impounded water percolates away by about January–February (peninsular India) before high summer evaporation;
- provided with a waste weir / surplus escape and, on the bund, standard earthen-dam features.



10.3 ADVANTAGES & LIMITATIONS

Advantages. low-cost, decentralised recharge; improves well yields and drinking-water security; supports soil conservation and flood moderation; simple to build with local labour.

Limitations. effective only over permeable strata; a large share of the impounded water is lost to evaporation (studies in granitic-gneissic semi-arid India show only ~30–35% is actually recharged); silting of the bed steadily reduces the percolation rate; benefits are diffuse and hard to attribute; needs periodic desilting.

11. WASTE / SURPLUS WEIR — DESIGN

PREVIOUS YEAR QUESTIONS

Design a waste weir: catchment area 35 ha; flood depth over crest 0.6 m; rainfall intensity 50 mm/h; runoff coefficient 0.5.*** [IFoS 2017 | P1/2(d) | 10M]

A ***waste (surplus) weir*** is the masonry escape that passes surplus runoff over and above the storage capacity out of a tank, farm pond or contour bund, keeping the bund from being overtopped. Its crest is set at the full-tank (full-supply) level and its length is fixed from the weir formula for the design flood.

Design steps. (i) find the peak surplus discharge by the

***Rational method*, $Q = C \cdot I \cdot A / 360$;**

(ii) fix the allowable flood depth H over the crest;

(iii) solve the weir formula

$Q = C_w \cdot L \cdot H^{1.5}$ ($C_w \approx 1.71$ SI) for the crest length L;

(iv) add free-board and design the body, apron and wing walls.

⌘ *Waste-weir design (IFoS 2017)*

Full question. Design a waste weir: cumulative catchment area = 35 ha; flood depth over the crest = 0.6 m; rainfall intensity = 50 mm/h; runoff coefficient = 0.5.

Given:

- ***Cumulative catchment area*, A = 35 ha**

- ***Flood depth over the crest, H = 0.6 m***
- ***Rainfall intensity, I = 50 mm/h***
- ***Runoff coefficient, C = 0.5***

Peak surplus discharge: $Q = C \cdot I \cdot A / 360$

$= 0.5 \times 50 \times 35 / 360 =$ **2.43 m³/s**.

Crest length from $Q = C_w \cdot L \cdot H1.5$ ($C_w \approx 1.71$ SI)

$Q = 1.71 \cdot L \cdot H^{1.5}$ with H = 0.6 m ($H^{1.5} = 0.465$):

$L = Q / (1.71 \times 0.465)$ = 2.43 / 0.795 = **3.06 m (say 3.1 m)**.

Provide ~0.3 m free-board above the flood depth; design the weir body, downstream apron and 45° wing walls, keyed into the bund.

Answer: a surplus weir ≈ 3.1 m long passing 2.43 m³/s at 0.6 m head.

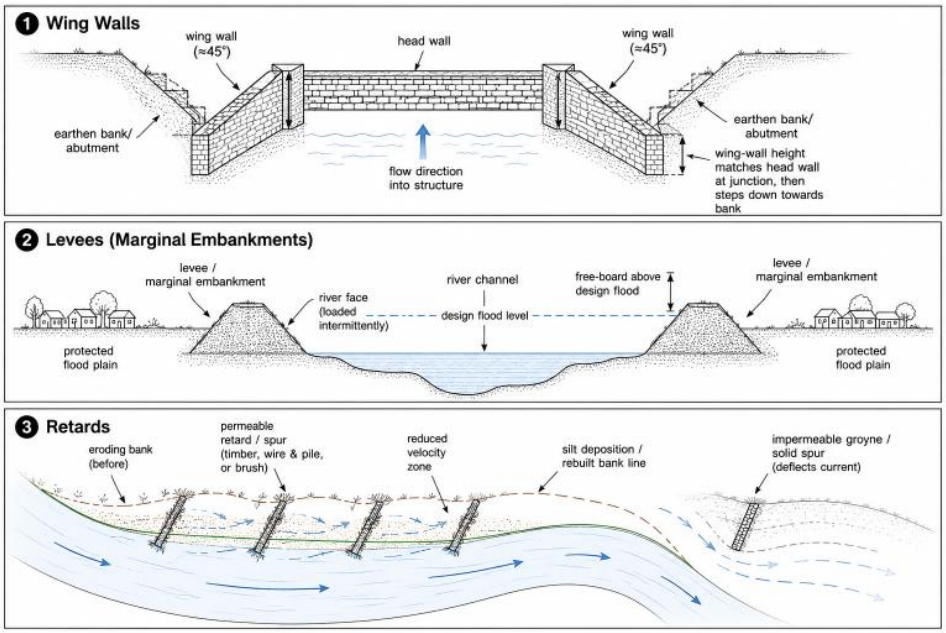
12. WING WALLS, LEVEES, RETARDS & APPURTENANCES

PREVIOUS YEAR QUESTIONS

State the adaptability and functions of levees and retards.*** [IFoS 2020 | P1/1(a) | 8M]

12.1 WING WALLS

Wing walls are the inclined (≈ 45°) walls at the ends of a spillway / weir that **retain the bank fill, guide the flow into the structure and protect the abutments from scour**. Their height at the junction with the head wall is fixed with the structure (see §4.4); they then splay outward and downward to the gully sides. They are essential wherever a masonry structure meets an earthen bank.



12.2 LEVEES (MARGINAL EMBANKMENTS)

A ***levee*** (marginal embankment / flood bank) is an earthen embankment built roughly parallel to a river, set back from the bank, to **confine flood flow and protect the flood plain, land and settlements behind it**.

Adaptability & functions. suited to wide alluvial flood plains where a river spills in flood; it raises the containing bank so the flood passes within the leveed channel. Design is like a small earth dam, but the upstream (river) face is loaded only intermittently; free-board above the design flood, side slopes, and protection of the river face against wave / current attack are provided.

© Hornbill Classes
+91 78802-71423 Hornbillclasses@gmail.com

12.3 RETARDS

A ***retard*** is a **permeable bank-protection device** — permeable spurs / groynes, timber or wire-and-pile fences, tree / brush screens — projecting from or laid along an eroding bank.

Adaptability & functions. used on alluvial river bends and eroding banks where full armour is costly. By offering resistance they **reduce the flow velocity next to the bank and induce silt deposition**, so the bank line is protected and gradually rebuilt. They are cheaper and more flexible than solid revetment but give slower, partial protection — contrast with impermeable spurs / groynes that deflect the current away.

13. STABILITY ANALYSIS — RETAINING WALLS & GRAVITY DAMS

PREVIOUS YEAR QUESTIONS

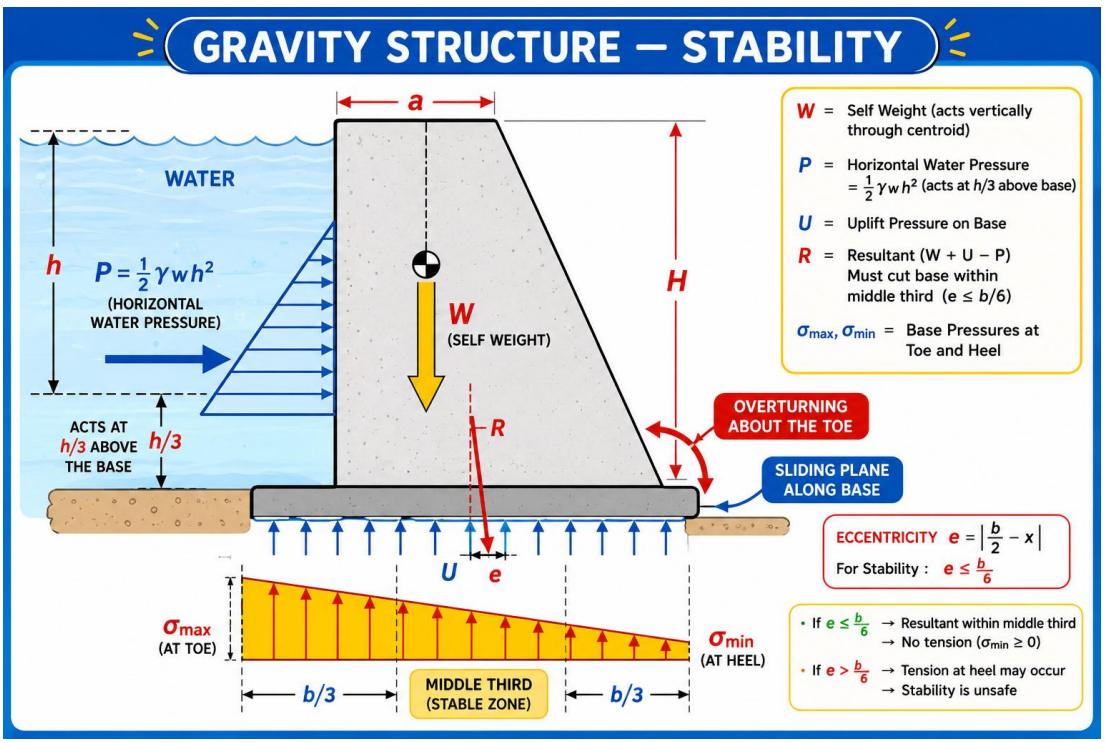
- Explain the stability analysis of retention walls and dams.*** [IFoS 2019 | P1/1(d) | 8M]
- Test the structural stability of a straight gravity masonry dam (top 1.6 m, base 3.2 m, height 6.2 m, water 5.6 m, μ=0.5, bearing capacity 25000 kg/m²).***

[OPSC·CSE 2016-17 | Q7(c) | 30M]

Retaining walls and gravity dams are **gravity structures**: they hold back the horizontal thrust of water / earth by sheer self-weight. Both are checked against the same four modes of failure ***overturning, sliding, tension (no-tension / middle-third), and crushing (compression)***; dams add a piping / uplift check. The governing idea is that the resultant of all forces must stay within the **middle third** of the base so that no tension develops.

13.1 FORCES

- **Self-weight W :** acts vertically through the centroid of the section (the stabilising force).
- **Horizontal thrust ΣH :** water pressure P = ½γw h² (at h/3 above base) for a dam; active earth pressure P = ½ K_a γ H² for a retaining wall.
- **Uplift U :** (dams) hydrostatic pressure on the base, reducing the effective weight.



∑ DERIVATION — The middle-third (no-tension) rule

Set-up. *Take unit length of base, width b.* ***ΣV = net vertical force acting at eccentricity e from the base centroid.***

Base stress = direct + bending:

$\sigma = \Sigma V/A \pm M \cdot y/I$,

with $A = b$, $I = b^3/12$, $y = b/2$, $M = \Sigma V \cdot e$.

$\sigma = \Sigma V/b \pm (\Sigma V \cdot e)(b/2)/(b^3/12) = (\Sigma V/b)(1 \pm 6e/b)$.

$\sigma_max = (\Sigma V/b)(1 + 6e/b)$ *at the toe;* $\sigma_min = (\Sigma V/b)(1 - 6e/b)$ *at the heel.*

No tension requires $\sigma_min \geq 0 \Rightarrow 1 - 6e/b \geq 0 \Rightarrow$ **e ≤ b/6**.

Hence the resultant, for all loading, must cut the base within the middle third.

13.2 THE FOUR STABILITY CRITERIA

Failure mode	Criterion (must satisfy)
Overturning	F.S. = ΣRM / ΣOM ≥ 2 (usual); ≥ 1.5 for masonry gully structures
Sliding	F.S. = μΣV / ΣH ≥ 1; with joint shear, shear-friction factor SFF = (μΣV + B·q)/ΣH ≥ 3–5
No tension	e ≤ b/6 (resultant in middle third)
Crushing	σ_max = (ΣV/b)(1+6e/b) ≤ allowable / bearing capacity
Piping (dams)	weighted-creep ratio Cw ≥ safe value; control uplift

NOTATION:

- F.S. = Factor of Safety
- ΣRM = sum of restoring moments (about the toe, from self-weight W)
- ΣOM = sum of overturning moments (about the toe, from water thrust P and uplift U)
- μ = coefficient of friction between base and foundation
- ΣV = sum of vertical forces (net downward force — self-weight minus uplift)
- ΣH = sum of horizontal forces (water thrust + earth pressure)
- SFF = Shear-Friction Factor (rigorous sliding check incl. base shear/bond)
- B, b = base width
- q = allowable shear/bond stress at the base joint
- e = eccentricity of the resultant from the base centroid
- σ_max, σ_min = maximum/minimum base stress at the toe and heel
- Cw = weighted-creep ratio (piping/seepage safety check)
- U = uplift force

13.3 RETAINING-WALL SPECIFICS

For a masonry retaining wall the backfill exerts $P = \frac{1}{2} K_a \gamma H^2$ at H/3; the section is proportioned (top width, base width, batter) so that the resultant of W and P stays within the middle third ($e \leq b/6$), $\sigma_max \leq$ safe bearing pressure, and $\mu\Sigma V \geq \Sigma H$. Cantilever / counterfort types add a base slab and (for H > 6 m) counterforts, with a key under the base to resist sliding.

13.4 GRAVITY-DAM SPECIFICS

Besides the four checks, the **principal stress** at the toe $\sigma_1 = \sigma_y \cdot \sec^2\phi - p' \cdot \tan^2\phi$ (ϕ = d/s face batter, p' = tail-water) must be within the allowable, and **uplift** is included in ΣV. Reservoir-empty and reservoir-full cases are both examined.

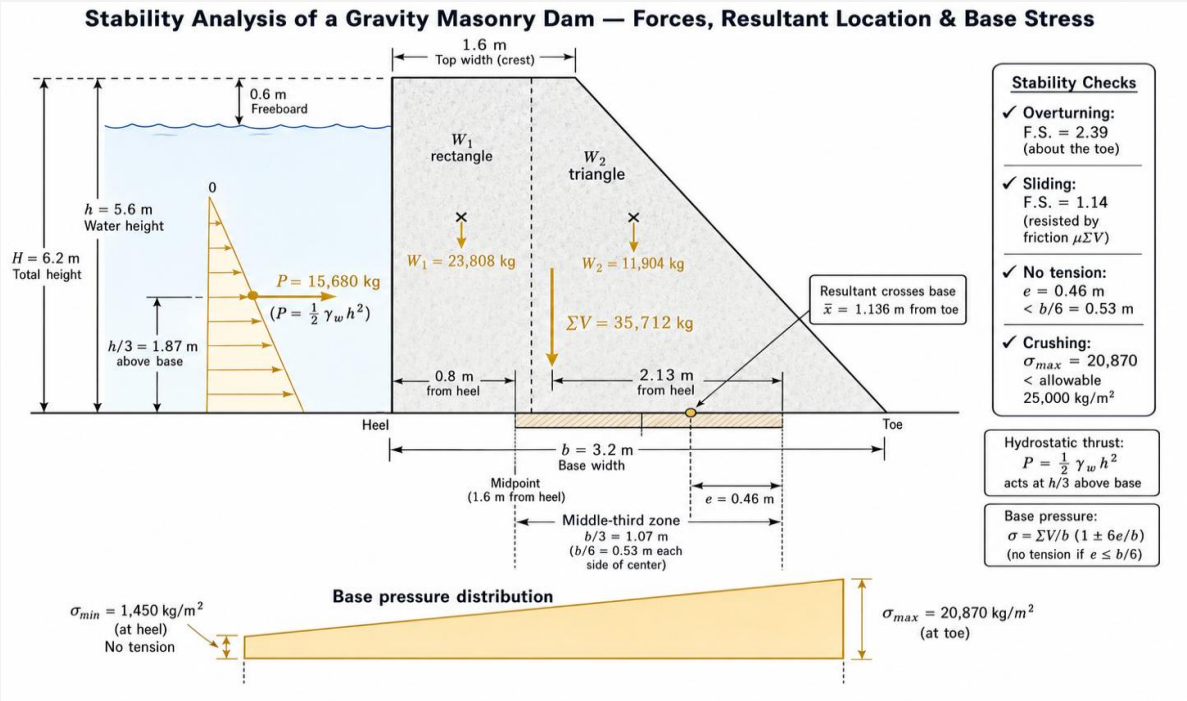
© Hornbill Classes
+91 78802-71423 Hornbillclasses@gmail.com

⌘ *Structural stability of a gravity masonry dam (OPSC 2016, 30 M)*

Full question. Straight gravity masonry dam, trapezoidal section: top width 1.6 m, base width 3.2 m, height 6.2 m, water impounding height 5.6 m, μ = 0.5, bearing capacity 25000 kg/m². Test its stability. (Assume u/s face vertical; masonry γ = 2400 kg/m³; uplift neglected.)

Given:

- ***Top width = 1.6 m***
- ***Base width, b = 3.2 m***
- ***Total height = 6.2 m***
- ***Water impounding height, h = 5.6 m***
- ***Coefficient of friction, μ = 0.5***
- ***Safe bearing capacity = 25,000 kg/m²***
- ***Assumptions: upstream face vertical; masonry unit weight γ = 2,400 kg/m³; uplift neglected***



Weights (per m):

rectangle W_1 = 1.6×6.2×2400 = 23808 kg at 0.8 m from heel;

d/s triangle W_2 = ½×1.6×6.2×2400 = 11904 kg at 2.13 m from heel.

ΣV = 35 712 kg.

Water thrust $P = ½\ \gamma w\ h^2$

= ½×1000×5.6²

= 15 680 kg at h/3 i.e 1.87 m above base.

① ***Overturning:***

- Restoring moment, ΣRM = W_1 × (lever arm from toe) + W_2 × (lever arm from toe) = 23,808 × (3.2 − 0.8) + 11,904 × (3.2 − 2.13) = 23,808 × 2.4 + 11,904 × 1.07 ≈ 69,837 kg·m
- Overturning moment, ΣOM = P × (lever arm above base) = 15,680 × 1.87 = 29,269 kg·m

ΣRM (about toe) = 69 837, ΣOM

= 15 680×1.87 = 29 269 kg·m ⇒ F.S. = **2.39 (>2 ✓)**.

② Sliding:

F.S. = μΣV/P

= 0.5×35 712 / 15 680 = **1.14 (>1 ✓)**

③ Tension:

$\bar{x} = (\Sigma RM - \Sigma OM)/\Sigma V$

$= 40\,568/35\,712 = 1.136\ m$ *from toe*;

$e = b/2 - \bar{x} = 1.6 - 1.136$

$= 0.46\ m < b/6 = 0.53\ m \Rightarrow$ **no tension ✓**

④ Crushing:

$\sigma_max = (\Sigma V/b)(1+6e/b)$

$= (35\,712/3.2)(1.87) =$ **20 870 kg/m² < 25 000 ✓**

σ_min = 1450 kg/m² (>0)

Conclusion: the dam is safe against overturning, sliding, tension and crushing — hence structurally stable.

14. WATERSHED HYDROLOGY FOR DESIGN & ALLIED STATE-PSC NUMERICALS

PREVIOUS YEAR QUESTIONS

- Watershed 1000 ha, slope 1.5%; 30-yr 24-h rainfall 76.2 mm; runoff (curve number) 31.4 mm; L:W = 3.5:1. Determine time to peak and peak discharge.*** [IFoS 2025 | P1/2(c)(i) | 10M]
- Reduce annual soil loss from 20 to 10 t/ha·yr; slope-length exponent 0.5; find the maximum slope length.*** [OPSC·CSE 2024-25 | Q9 (part)]
- Bench terraces on 15% slope, VI = 1.5 m, batter 1:1: length, earthwork per ha, area lost.*** [OPSC·CSE 2024-25 | Q18 (part)]

14.1 RUNOFF BY THE SCS CURVE-NUMBER METHOD

The runoff depth is $Q = (P - 0.2S)^2 / (P + 0.8S)$, with $S = (25400/CN) - 254$ (mm). It converts a design rainfall P and a curve number CN (soil-cover-AMC index) into the runoff volume that a farm pond or spillway must handle.

14.2 SCS TRIANGULAR HYDROGRAPH — TIME TO PEAK & PEAK DISCHARGE

For a small ungauged watershed the design hydrograph is idealised as a **triangle**.

Time of concentration t_c (e.g. Kirpich, t_c = 0.0195 L^0.77 S^−0.385, L in m, t_c in min);
lag t_l = 0.6 t_c; unit duration D ≈ 0.133 t_c;

Time to peak $T_p = D/2 + t_l$; **Peak discharge** $Q_p = 0.208 \cdot A \cdot Q / T_p$ (Qp in m³/s, A in km², Q runoff in mm, Tp in hr).

⌘ *Time to peak & peak discharge (IFoS 2025)*

Full question. Watershed area 1000 ha, average slope 1.5%, L:W = 3.5:1; curve-number runoff = 31.4 mm. Determine the time to peak and the peak discharge.

Given:

- Watershed area, A = 1000 ha = 10 km²
- Average slope, S = 1.5%
- Length : Width ratio, L:W = 3.5:1
- Curve-number runoff, Q (rainfall excess) = 31.4 mm

© Hornbill Classes
+91 78802-71423 Hornbillclasses@gmail.com

Geometry:
$A = 10\ km^2$;
with $L = 3.5\ W$ and
$L \cdot W = 10\ km^2 \Rightarrow$
$W = 1.69\ km,\ L = 5.92\ km\ (5920\ m)$.
Time of concentration (Kirpich): $t_c = 0.0195 \times 5920^{0.77} \times 0.015^{-0.385} \approx 79\ min = 1.31\ h$;
$t_l = 0.6\ t_c = 0.79\ h$; $D = 0.133\ t_c = 0.175\ h$.
Time to peak $Tp = D/2 + t_l = 0.088 + 0.79 =$ **≈ 0.88 h (~53 min)**.
Peak discharge $Qp = 0.208 \times 10 \times 31.4 / 0.88 =$ **≈ 74.6 m³/s**.
Note: the value depends on the t_c formula adopted (Kirpich used here); state the assumption in the exam.

14.3 USLE — EFFECT OF SLOPE LENGTH

In the Universal Soil-Loss Equation A = R·K·L·S·C·P, with other factors fixed the loss varies as A ∝ (slope length)^m.

⌘ Maximum slope length to halve soil loss (OPSC 2024-25)

Full question. Measured annual soil loss = 20 t/ha·yr on 8% slope, 84 m slope length. With the slope-length exponent m = 0.5 and all other factors constant, find the maximum slope length that reduces the loss to 10 t/ha·yr.

Given:

- *Initial annual soil loss,* $A_1 = 20\ t/ha{\cdot}yr$
- *Slope* $= 8\%$
- *Initial slope length,* $L_1 = 84\ m$
- *Slope-length exponent,* $m = 0.5$
- *Target annual soil loss,* $A_2 = 10\ t/ha{\cdot}yr$

$A_2/A_1 = (L_2/L_1)^m$
$\Rightarrow 10/20 = (L_2/84)^{0.5}$
$\Rightarrow 0.5 = (L_2/84)^{0.5}$
$\Rightarrow L_2/84 = 0.25 \Rightarrow L_2 =$ **21 m** (shorten the slope, e.g. by bunds/terraces, to ≤ 21 m).

14.4 BENCH-TERRACE NUMERICALS

For a bench terrace of vertical interval VI on a land slope S (%): horizontal spacing (width) **HI = 100·VI/S**; length per hectare = 10000/HI; earthwork (cut = fill) ≈ **1250·VI** m³/ha (average cut depth VI/4); area lost = (batter width)/HI.

⌘ Bench-terrace length, earthwork & area lost (OPSC 2024-25)

Full question. Hill slope 15%, bench terraces at vertical interval 1.5 m, batter slope 1:1. Determine (i) length of terrace per ha, (ii) earthwork per ha, (iii) area lost.

Given:

- *Hill slope,* $S = 15\%$
- *Vertical interval,* $VI = 1.5\ m$
- *Batter slope* $= 1:1$

Horizontal spacing $HI = 100 \times 1.5/15 = 10\ m$.
Length per ha $= 10000/HI = 10000/10 =$ **1000 m/ha**.
Earthwork $= 1250 \times VI = 1250 \times 1.5 =$ **1875 m³/ha**.
Batter width (riser height VI × 1 for 1:1) $= 1.5\ m$; *area lost* $= 1.5/10 =$ **15%**.

15. PYQ COVERAGE MATRIX

Every previous-year question in the chapter file is answered in this chapter — the matrix below maps each one to its section. N = *numerical*.

A | UPSC IFoS (Section A)

Year	Part | Marks	Topic	§	Type
2025	1(d) | 8	Trickle & flood spillway — earth dam	7	T
2025	2(c) | 15	Time to peak & peak discharge (N) + box-inlet size (N)	14, 4	N
2024	2(c) | 20	Design a drop spillway (stone masonry)	4	N
2024	3(b) | 15	Pond capacity from contours	9	N
2023	1(c) | 8	Percolation tank — purpose/adv/limitations	10	T
2023	3(c) | 15	Height of wing wall of drop structure	4, 12	N
2022	3(a) | 15	Check dam — uses, planning & design	8	T
2021	2(b·ii) | 10	Drop-inlet pipe spillway — pipe area	6	N
2021	3(c) | 20	Drop spillway — objectives, adv/lim, design	4	T/N
2020	1(a) | 8	Adaptability/functions: drop, chute, levees, retards	4,5,12	T
2020	2(b) | 15	Pond volume at 100% & 50% depth	9	N
2019	1(d) | 8	Stability of retention walls & dams	13	T
2019	2(b) | 10	Measures for controlling gully formation	2	T
2019	3(c) | 10	Types of spillways in gully control — compare	3	T
2019	3(d) | 10	Dug-out farm-pond excavation volume	9	N
2018	3(d) | 10	Design procedure of permanent SC structures	3	T
2018	4(c) | 10	Farm ponds — utility, types, site selection	9	T
2017	2(d) | 10	Design a waste weir	11	N
2017	3(c) | 10	Chute spillway — functions, limitations, design	5	T
2017	3(d) | 10	Types of farm ponds & design requirements	9	T
2017	4(d) | 10	Gully-control methods & design steps	2,3	T
2016	2(a) | 10	Drop-inlet spillway — working & situation	6	T

B | State PSC (Section B)

Exam / Year	Marks	Topic	§	Type
OPSC-CSE 2024-25	15	Drop/chute/drop-inlet differences + USLE slope length	3,14	T/N
OPSC-CSE 2024-25	20	Gully erosion — stages, classification, conditions	1	T
OPSC-CSE 2024-25	20	Farm pond define + contour capacity + bench terrace	9,14	T/N
OPSC-Forest 2023-24	20	Farm pond — components & design criteria	9	T
OPSC-CSE 2022-23	8	Permanent gully-control structures (sketch)	3	T
OPSC-CSE 2022-23	8	Farm-pond design steps + percolation pond uses	9,10	T
UK-PSC RFO 2021	10	Functions of permanent SC structures; drop vs chute	3	T
OPSC-CSE 2020-21	12	Farm-pond capacity from contours	9	N

© Hornbill Classes
+91 78802-71423 Hornbillclasses@gmail.com

OPSC-CSE 2020-21	5	Temporary gully-control measures	2	T
OPSC-CSE 2018-19	10	Drop vs drop-inlet pipe spillway	4,6	T
OPSC-CSE 2018-19	20	Conditions for permanent gully structures	1,3	T
OPSC-CSE 2016-17	30	Gravity masonry dam — test stability	13	N
OPSC-CSE 2015-16	10	Chute & drop spillway (RS/GIS part → other ch.)	5	T
OPSC-Forest 2015-16	10	Classify SC structures; drop-spillway parts	1,4	T
OPSC-Forest 2015-16	10	Farm-pond types; embankment; top-width formula	9	T
UK-PSC RFO 2015	10	Structural components of a drop spillway	4	T
UK-PSC RFO 2012	10	Temporary structures + check-dam suitability	2,8	T
UK-PSC RFO 2012	10	Drop spillway — functions, adv/limitations	4	T

✦ **CROSS-CHAPTER NOTE**
The OPSC 2015-16 question also asks about **remote sensing & GIS in water-resources development** — this belongs to the Remote-Sensing/GIS chapter, not Chapter 3, and is only cross-referenced here.

16. QUICK-REVISION FORMULA SHEET

Every working formula of the chapter, gathered in one place for last-day revision. *SI units; Q in m^3/s, lengths in m, areas in ha or m^2 as noted.*

Quantity	Formula
Peak runoff (Rational)	Q = C·I·A / 360 (I in mm/h, A in ha)
Rectangular weir / notch	Q = 1.71 | L | h^1.5 (free flow; some texts C = 1.72)
Temporary-check notch	Q = 0.0171 | L | H^1.5 (Q in L/s, L,H in cm)
Check-dam spacing	spacing = eff. height ÷ (original − stable bed slope)
Drop-spillway checks	h/F ≤ 0.5 (max 0.75); L/h ≥ 2; free-board 0.15–0.30 m
transverse sill S	S = h/3
longitudinal / end sill HL	HL = h/4
head wall / extension	HB = F + S; HE = F + S + h
head-wall extension E	E = greater of (3h + 0.6) and 1.5 F
wing/side wall junction J	J = greater of 2h and drop-based value
cut-off / toe wall C=T	C = 1.65(HL + 0.4F + 0.75)/4
Box inlet (drop spillway)	he ≤ 0.6 F; Q = 1.71·L·he^1.5, L = 3a (square, 3-side)
Hydraulic-jump sequent depth	$d_2 = (d_1/2)[\sqrt{(1+8Fr_1^2)} - 1]$, $Fr_1 = V_1/\sqrt{(g\,d_1)}$
SAF basin length	L_B = 4.5 d_2 / Fr_1^0.76; end sill = 0.07 d_2
Drop-inlet full-pipe flow	Q = a·√[2gH/(1 + K_e + K_c·L)]
Manning (chute channel)	V = (1/n)·R^(2/3)·S^(1/2), R = A/P
Pond volume (prismoidal)	V = (D/6)(A_top + 4A_mid + A_bottom)
Pond capacity (contours)	trap: $\Sigma(h/2)(A_i+A_{i+1})$; Simpson: $(h/3)[A_o+4\Sigma odd+2\Sigma even+A_n]$
Embankment top width	T = H/5 + 1.5 (m) or 1.67·√H (larger governs); free-board 15%, settlement 5%
Waste / surplus weir	Q = C·I·A/360; L = Q/(1.71·H^1.5)

SCS curve-number runoff	Q = (P−0.2S)²/(P+0.8S), S = 25400/CN − 254 (mm)
Time of concentration (Kirpich)	t_c = 0.0195 L^0.77 S^−0.385 (min, L in m)
SCS triangular hydrograph	t_l=0.6t_c; Tp=D/2+t_l; Qp=0.208·A·Q/Tp (A km², Q mm)
USLE	A = R·K·L·S·C·P; A ∝ (slope length)^m
Bench terrace	HI = 100·VI/S; length = 10^4/HI; earthwork ≈ 1250·VI m^3/ha
No-tension (middle third)	σ = (ΣV/b)(1 ± 6e/b); no tension if e ≤ b/6
Overturning F.S.	ΣRM/ΣOM ≥ 2 (≥1.5 masonry gully structures)
Sliding F.S.	μΣV/ΣH ≥ 1; SFF = (μΣV + B·q)/ΣH ≥ 3–5
Weighted-creep (piping)	Cw = (ΣLv + ΣLh/3)/H ≥ safe value

Golden rules to recall in the hall. *(1) Fall height selects the structure: <1 m temporary, ≤3 m drop, 3–6 m chute, >6 m drop-inlet. (2) Every permanent structure = hydrologic + hydraulic + structural design. (3) Two causes of failure: too little capacity, too little energy dissipation. (4) Stability = no tension (e ≤ b/6) + safe against overturning, sliding & crushing.*

© Hornbill Classes
+91 78802-71423 Hornbillclasses@gmail.com

CHAPTER

4

FLOOD CONTROL, WATERSHED MANAGEMENT & LAND DEVELOPMENT

Stream ordering · Watershed management, prioritization & programmes · Water harvesting · Flood routing (Muskingum) · Land grading & earthwork · Drought · Wind erosion & sand-dune fixation — full theory, derivations & worked numericals

OFFICIAL SYLLABUS — *Chapter 4 scope*

Flood routing (Muskingum method), storage & detention reservoirs. Watershed management - investigation, planning, prioritization & implementation; integrated watershed approach; stream ordering. Water harvesting & moisture conservation (in-situ + ex-situ) for dryland & non-arable areas. Land development - levelling, plane method, factors & survey for land grading; estimation of earth volumes & costing. Drought management. Sand-dune fixation. Watershed development programmes (Hariyali, WARASA–Jan Sahbhagita). Wind-erosion process - soil-particle movement and surface wind-velocity reduction.

Chapter Outline

1 Watershed — Concept, Classification, Characteristics & Stream Ordering

2 Watershed Management — Principles, Objectives & Integrated Approach

3 Watershed Investigation, Planning & Implementation

4 Watershed Delineation & Prioritization (with RS & GIS)

5 Watershed Development Programmes, People's Participation & M&E

6 Water Harvesting & Moisture Conservation — In-situ

7 Water Harvesting — Ex-situ Structures, Runoff Inducement, Components & Steps

↳ Source — Watershed Planning & Management, L19 (p.154–159), L20 (p.160–163), L13 (p.96–105), L14 (p.106–113).

8 Flood Routing — Concept, Elements & Reservoir (Storage) Routing

9 Muskingum Channel Routing — Premise, K & x Estimation + Numerical

10 Flood Control — Storage & Detention Reservoirs & Watershed Flood Measures

11 Drought Management

12 Land Development I — Land Grading / Levelling: Factors, Survey & Plane Method

13 Land Development II — Earthwork Computation, Costing & Machinery

14 Wind Erosion Process & Sand-Dune Fixation

15 PYQ Coverage Matrix

16 Quick-Revision Formula Sheet

◆ **WEIGHTAGE & TREND ANALYSIS (IFoS 2016–2025)**

Chapter 4 is a high-yielding part of Paper I, Section A. Between 2016 and 2025 the IFoS examination drew 28 questions from this chapter, with a further 36 from State Forest / engineering services (OPSC, UK-PSC, HP-PSC, AP-PSC). Watershed management & programmes, water harvesting and land development dominate; roughly a third of all questions are numerical.

Theme	IFoS Qs	Typical form	Priority
Watershed mgmt, planning & programmes	9	Principles / objectives / WARASA vs Hariyali	★★★
Water harvesting & moisture conservation	5	In-situ / ex-situ / components	★★★
Land development (grading & earthwork)	6	Plane method + earthwork numericals	★★★
Flood routing & flood control	3	Muskingum K&x + reservoirs	★★
Watershed characteristics & prioritization	3	Stream ordering + RS/GIS prioritization	★★
Drought management	1	Types + measures	★★
Wind erosion & sand dunes	3	Soil movement / velocity reduction / fixation	★★

© Hornbill Classes
+91 78802-71423 Hornbillclasses@gmail.com

1. WATERSHED — CONCEPT, CLASSIFICATION, CHARACTERISTICS & STREAM ORDERING

PREVIOUS YEAR QUESTIONS

- Describe the importance of stream ordering in watershed study. [IFoS 2020 | P1 Q3(a) | 10M]
- Conservation measures for the treatment of a watershed having maximum stream order III. [IFoS 2021 | P1 Q3(b) · 10M]
- Define a watershed and describe the watershed-management approach. [UKPSC RFO 2021 | Q1(iii) | 10M]
- What is a watershed and why is it the basic unit for agricultural development? [OPSC Forest 2015 | Q2(b) | 10M]

Chapters 1–3 dealt with erosion processes and the structures that arrest concentrated flow. This chapter steps up to the management unit on which all those measures are planned and integrated — the watershed.

1.1 CONCEPT AND DEFINITION

A watershed (catchment / drainage basin) is the area of land, enclosed by a ridge line (water divide), that drains all rainfall falling on it to a single common outlet. In British usage 'watershed' means the ridge line itself; in American usage it is a synonym for catchment or basin. Here it denotes a small hydrologic unit that drains its rainwater into one stream — hydrologically independent in terms of its surface water.

1.2 WHY THE WATERSHED IS THE BASIC PLANNING UNIT

It is a natural hydrologic unit: the effect of any land treatment on runoff, erosion and groundwater can be measured at the single outlet. Its resources - land, water, vegetation - are interdependent within one boundary, permitting an integrated, area-based (ridge-to-valley) plan instead of piecemeal works.

1.3 CLASSIFICATION BY SIZE (BALI, 1980; AISLUS, 1990)

Category	Area
Macro-watershed	500 – 2,000 km²
Sub-watershed	100 – 500 km²
Milli-watershed	10 – 100 km²
Mini-watershed	1 – 10 km²
Micro-watershed	< 1 km²

Watersheds are also classified by shape, land use/land cover and drainage (most Indian watersheds are mixed in land use).

1.4 PHYSICAL (GEOMORPHIC) CHARACTERISTICS

Runoff behaviour is governed by area, slope, shape and length, plus shape descriptors:

Parameter	Expression	Note
Form factor	A / L^2	< 1
Shape factor	L^2 / A	> 1
Circularity ratio	$12.57\ A / P^2$	≤ 1

Elongation ratio	1.128 √A / L	≤ 1
Compactness coefficient	0.2821 P / √A	≥ 1

A circular watershed delivers runoff from all parts together → higher, sharper flood peak; an elongated watershed spreads runoff over time → lower peak.

1.5 STREAM (CHANNEL) ORDERING — STRAHLER'S SYSTEM

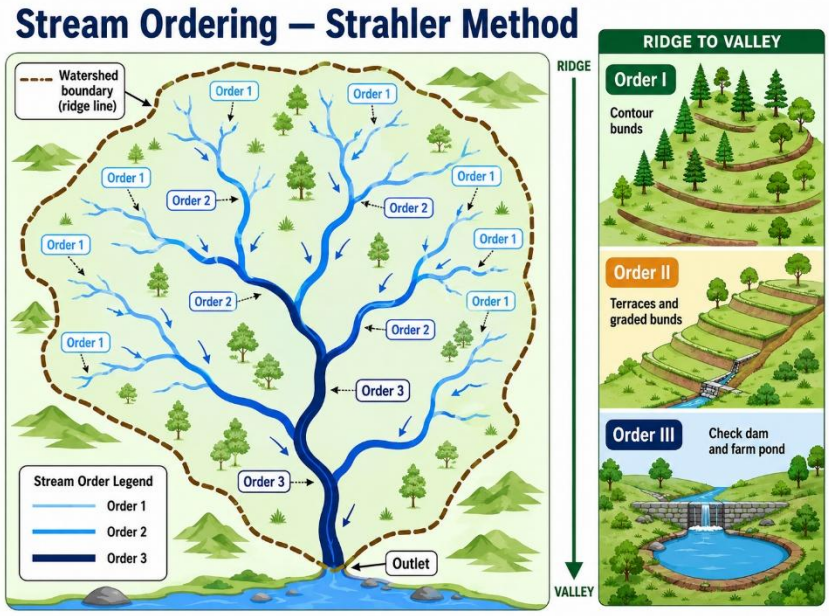
Fingertip tributaries with no branches are order 1; the junction of two order-1 streams forms order 2; two order-2 streams form order 3, and so on. The highest order at the outlet = the order of the watershed.

∑ Morphometric laws & indices

Bifurcation ratio Rb = **Nw / N(w+1)** — streams of order w to those of next higher order; normally 3–5.
Horton's law of stream numbers: Nw = $Rb^{(W-w)}$ (streams decrease geometrically as order rises).
Stream-length ratio RL = **Lw / L(w−1)** — normally 1.5–3.5.
Drainage density Dd = **L / A** — total channel length of all orders per unit area.
Length of overland flow L_o = **1 / (2 Dd)** (Horton, 1945).

1.6 IMPORTANCE OF STREAM ORDERING (ANSWERS IFOS 2020·3 (A))

It indicates the size, drainage development and relative discharge of the basin; it is the basis of morphometric analysis (bifurcation ratio, drainage density, stream-length ratio) used in watershed prioritization; and it guides the ridge-to-valley treatment plan.



1.7 TREATMENT OF A WATERSHED OF MAXIMUM STREAM ORDER III (ANSWERS IFOS 2021 | 3(B))

- **Order I (upper ridges/slopes) :** agronomic & vegetative measures - contour cultivation, contour bunding, contour trenches, afforestation - to cut runoff at source.
- **Order II (middle reaches) :** graded bunds, terraces, diversion drains, temporary gully-control (brushwood/loose-rock check dams).
- **Order III (lower/main drainage) :** permanent gully-control structures, check dams, percolation tanks, farm ponds and water-harvesting structures for storage & recharge.

☞ **Standard morphometry numerical (textbook-type, illustrates §1.5)**
A fourth-order watershed of area 50 km² has N_1=80, N_2=20, N_3=5, N_4=1 and total channel length 120 km. Find mean bifurcation ratio, drainage density and length of overland flow.

© Hornbill Classes
+91 78802-71423 Hornbillclasses@gmail.com

Bifurcation ratio Rb (1,2) = 80/20 = 4.0;

Bifurcation ratio Rb (2,3) = 20/5 = 4.0;

Bifurcation ratio Rb (3,4) = 5/1 = 5.0

Mean bifurcation ratio Rb = 4.33 (within 3–5 ✓).

Drainage density Dd = L/A = 120/50 = 2.4 km/km².

Length of overland flow L_0 = 1/(2Dd) = 1/ (2×2.4) = 0.208 km ≈ 208 m.

2. WATERSHED MANAGEMENT — PRINCIPLES, OBJECTIVES & INTEGRATED APPROACH

PREVIOUS YEAR QUESTIONS

- Principles and objectives of watershed management (prioritization criteria → §4).*** [IFoS 2025 | P1 Q3(a) | 15M]
- What is the integrated watershed management approach? Explain its objectives.** [IFoS 2018 | P1 Q1(c) | 8M]
- Main objectives of a watershed management programme (survey → §3).** [IFoS 2016 | P1 Q2(b) | 10M]
- Define / approach / components of watershed management.* [OPSC 2020 | 7(a) / 2015 | 7(c); UKPSC 2021]

2.1 DEFINITION

Watershed management is the study of the relevant characteristics of a watershed aimed at the sustainable distribution of its resources creating and implementing plans, programmes and projects that sustain and enhance watershed functions affecting the plant, animal and human communities within the boundary.

2.2 OBJECTIVES

Control damaging runoff and land degradation → conserve soil and water; use runoff productively; protect and improve watershed land for sustained production; protect and enhance the water resource; check erosion and reduce sediment yield; rehabilitate deteriorating lands; moderate downstream flood peaks; increase infiltration and groundwater recharge; and raise production of timber, fodder and livestock.

2.3 PRINCIPLES

Treat every parcel of land according to its capability; maintain a protective soil cover; utilise each drop of rain where it falls and safely dispose of the surplus; follow a ridge-to-valley treatment sequence; and ensure people's participation and sustainability.

2.4 INTEGRATED WATERSHED MANAGEMENT (IWM) (ANSWERS IFOS 2018·1(C))

IWM treats the watershed as a single hydrologic unit and manages its land, water and vegetation together through an interdisciplinary, participatory approach. Objectives: conserve soil and moisture in-situ; harvest and recharge surplus water; stabilise and raise crop, fodder and fuel-wood production; restore ecological balance; and improve rural livelihoods so benefits (many of which are losses prevented, e.g. reduced reservoir sedimentation) are shared equitably across upstream and downstream users.

2.5 PROBLEMS & CONSTRAINTS (WPM L2, BRIEF)

Land degradation in rainfed areas; inequitable benefit-sharing (women, marginal and landless gain least; upstream harvesting can starve downstream reservoirs); water scarcity; weak baseline data; and tribal-area deprivation. (Issues/challenges & people's participation continued in §5.)

2.6 PROBLEMS & CONSTRAINTS (WPM L2, BRIEF)

3. WATERSHED INVESTIGATION, PLANNING & IMPLEMENTATION

PREVIOUS YEAR QUESTIONS

- What survey is required while planning for watershed development?** [IFoS 2016 | P1 Q2(b) | 10M]
- Procedure to conduct a topographical survey of a watershed by the direct contour method.** [IFoS 2017 | P1 Q1(d) | 8M]
- Investigation, planning & implementation considerations and steps.** [OPSC Forest 2019 | 2(a); OPSC 2020 | 7(b); APPSC 2012 | Q6 | 40M]

3.1 THE THREE PHASES

Watershed development proceeds through Investigation **(survey)** → Planning → Implementation, followed by monitoring and evaluation.

3.2 INVESTIGATION / SURVEY (ANSWERS IFoS 2016 | 2(B))

Data are grouped (WPM L7) as: climatic (rainfall, temperature, evaporation); physiographic & topographic (drainage geomorphology, slope, DEMs for routing/delineation); soils and land-capability; land-use / land-cover (aerial photos, satellite imagery, ground survey); hydrologic (runoff, sediment); and a socio-economic survey of the watershed community (holdings, livelihoods, willingness to participate).

3.3 PLANNING — FIVE SEQUENTIAL STEPS

(1) Monitor and evaluate past activities; identify problems and opportunities.
(2) Establish objectives and constraints from the problem analysis; formulate strategies.
(3) Identify alternative management practices within the constraints.
(4) Appraise their environmental, social and economic impacts and the uncertainty (sensitivity analysis).
(5) Rank/priorities the alternatives and prepare the ridge-to-valley treatment plan with a people's action plan and cost–benefit appraisal.

3.4 IMPLEMENTATION

Works are executed with community participation, phased ridge-to-valley, with capacity building - then sustained through monitoring, maintenance and evaluation (§5).

3.5 TOPOGRAPHICAL SURVEY BY THE DIRECT CONTOUR METHOD (ANSWERS IFoS 2017 | 1(D))

In the direct (instrument) method, points of equal elevation are located on the ground with a level and staff: a benchmark RL is established, the required contour RL fixed, and the staff moved until that reduced level is read; the point is pegged, and a series of such pegged points is joined to trace each contour directly on the ground. Repeating for successive contour intervals yields an accurate contour map — the base for delineation, drainage analysis and treatment planning.

© Hornbill Classes
+91 78802-71423 Hornbillclasses@gmail.com

4. WATERSHED DELINEATION & PRIORITIZATION (WITH RS & GIS)

PREVIOUS YEAR QUESTIONS

- Watershed prioritization for soil-erosion & sediment-yield using remote sensing and GIS.*** [IFoS 2023 | P1 Q4(c) | 20M]
- Criteria used for prioritizing watersheds.*** [IFoS 2025 | P1 Q3(a) | 15M]
- Role of RS & GIS in watershed planning, development & evaluation.*** [OPSC 2023 | 16(b); 2022 | 16(a); 2017 | 7(c)]

4.1 WATERSHED DELINEATION (WPM L9)

On a contour/topographic map the boundary is drawn by joining the ridge/high points (hill tops, ridge lines, saddles) around the stream contour lines 'point upstream', and the highest point upstream is the head. In GIS a DEM (from digitised contours or ASTER/SRTM) is processed — fill sinks → flow direction (D8/D∞) → flow accumulation → stream definition → outlet → automatic delineation (ArcSWAT / ArcHydro / TauDEM).

4.2 CONCEPT OF PRIORITY WATERSHEDS

In a large watershed the whole area cannot be treated at once; sub-watersheds with the greatest degradation/erosion are selected first for treatment according to need these are priority watersheds.

4.3 METHODS / CRITERIA FOR PRIORITIZATION

(1) Reconnaissance survey : approximate relative erosion status;
(2) Detailed soil & land-use surveys;
(3) Silt-load measurement : actual sediment from each sub-watershed over 3–5 years (most direct, but slow);
(4) Remote-sensing techniques : satellite imagery + interpretation for rapid identification in large watersheds.

∑ Sediment-Yield-Index (erosion-intensity) ranking (WPM L10)

1. Map erosion-intensity units (EIU) and grade by increasing severity (least = weight 1; more severe = 2,3,4…); apply a delivery ratio (0.40–0.95) and distance-from-reservoir weights (Table 10.1: <8 km = 50 … >161 km = 5).
2. For each sub-watershed, weighted product = Σ(area of each EIU × its weight).
3. Sum → the sub-watershed's sediment-yield / erodibility index.
4. Rank by index → highest = Priority 1.

Morphometric route: linear parameters (drainage density, stream frequency, bifurcation ratio, drainage texture, length of overland flow) are directly related to erodibility - highest value = rank 1; the compound parameter (mean of ranks) then orders the sub-watersheds.

4.4 ROLE OF RS & GIS (Answers IFoS 2023 | 4(C))

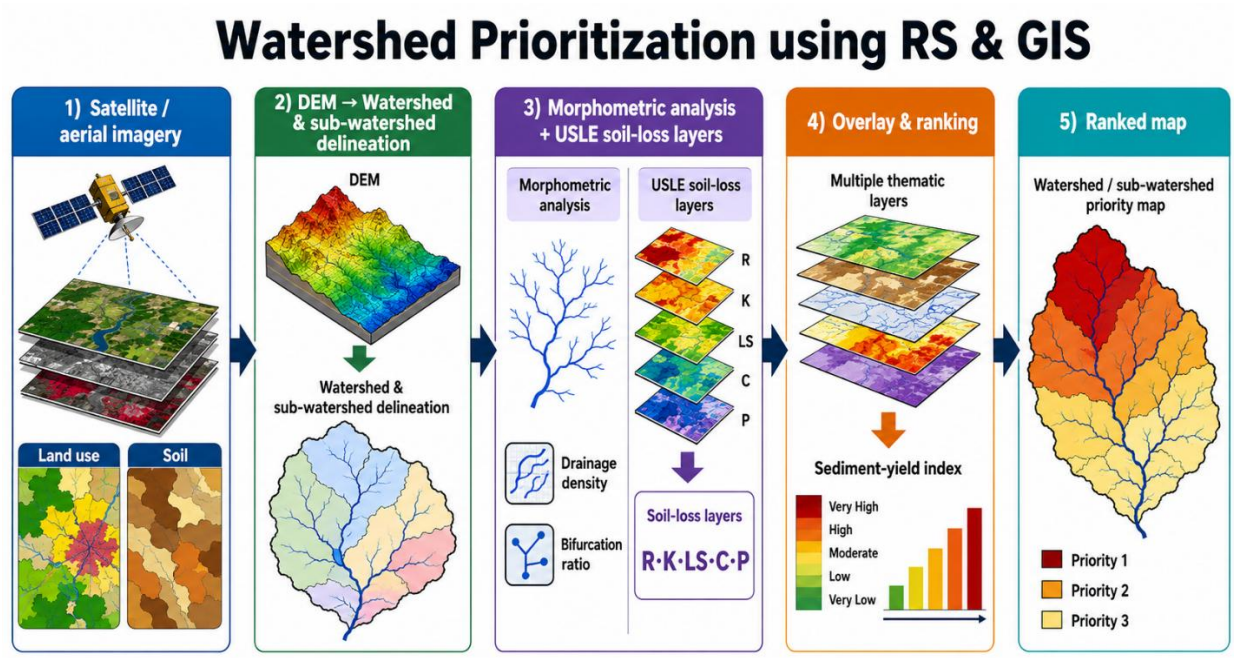
Remote sensing supplies multi-temporal land-use/land-cover, soil, slope and erosion data over large, inaccessible areas; GIS integrates these as thematic layers, delineates watersheds, computes morphometry from the DEM, and overlays the USLE factors **(R·K·LS·C·P)** to map soil loss and sediment yield the layers are combined to rank sub-watersheds and drive a decision-support prioritization, far faster and cheaper than field silt-load surveys.

☞ **Compound-parameter prioritization (textbook-type)**

Three sub-watersheds have morphometric ranks — **SW-A**: (Dd 2, Rb 1, Fs 2); SW-B: (3,3,3); SW-C: (1,2,1). Order them for treatment.

Compound value = **mean rank: A** = (2+1+2)/3 = 1.67; B = (3+3+3)/3 = 3.0; C = (1+2+1)/3 = 1.33.

Lowest compound value = highest erodibility = first priority → C → A → B.



5. WATERSHED DEVELOPMENT PROGRAMMES, PEOPLE'S PARTICIPATION & M&E

PREVIOUS YEAR QUESTIONS

- Differentiate 'WARASA – Jan Sahbhagita' and 'Hariyali' watershed development programmes.*** [IFoS 2024 | P1 Q2(a) | 10M]
- Guiding principles for watershed development projects as stipulated in the Common Guidelines.*** [IFoS 2022 | P1 Q1(a) | 8M]
- Role of people's participation in watershed development.** [IFoS 2017 | P1 Q1(a) | 8M]
- Gaps between planning and implementation of watershed programmes.** [OPSC 2017 | 7(d)]

5.1 EVOLUTION OF WATERSHED PROGRAMMES IN INDIA (BRIEF)

From the Soil Conservation Research, Demonstration & Training Centres of the 1950s → NWDPRA (National Watershed Development Project for Rainfed Areas, 1990-91) and IWDP (Integrated Wastelands Development Programme, 1995) → WARASA–Jan Sahbhagita (2000, the revised NWDPRA guidelines making implementation community-led) → Hariyali guidelines (2003) → NRAA (National Rainfed Area Authority, 2006) → the unifying Common Guidelines (2008) → IWMP (Integrated Watershed Management Programme, 2009-10) → WDC-PMKSY (Watershed Development Component–Pradhan Mantri Krishi Sinchayee Yojana, 2015-16), now WDC-PMKSY 2.0 (2021-26).

© Hornbill Classes
+91 78802-71423 Hornbillclasses@gmail.com

5.2 WARASA–JAN SAHBHAGITA (MINISTRY OF AGRICULTURE / DAC)

The revised NWDPRA guidelines (2000) — made 'more participatory, sustainable and equitable'. Implemented department-wise: SLNA → District Nodal Agency → Project Implementing Agency (PIA) → Watershed Development Team (WDT) → Watershed Committee/Association. Watershed ~1,000–5,000 ha; sequenced Preparatory (1 yr) → Works (3 yr) → Consolidation & Withdrawal; 1% corpus fund; favours blocks with <30% assured irrigation.

Full form & origin: WARASA stands for **Watershed Areas' Rainfed Agriculture(l) Systems Approach**; paired with 'Jan Sahbhagita' (people's participation), it named the 2000 revision of the NWDPRA guidelines issued by the Ministry of Agriculture, Department of Agriculture & Cooperation (Rainfed Farming Systems Division) — framed in conformity with the 'Common Approach/Common Principles for Watershed Development' that emerged from the Hanumantha Rao Committee (1994), so as to make NWDPRA implementation a genuine people's movement rather than an official-agency-led scheme.

Core operating principles: decentralization of procedures and flexibility in choice of technology; a ridge-to-valley treatment sequence; livelihood support to the landless, with equity for the poor and empowerment of women; convergence with other government and NGO schemes; and community mobilization towards self-reliant, sustainable development. Official agencies (SLNA, District Nodal Agency, PIA) act only as facilitators/coordinators — the Watershed Association/Committee itself plans, implements and evaluates the project, formalized through a Memorandum of Understanding between the Watershed Association and the District Nodal Agency/PIA.

5.3 HARIYALI (MINISTRY OF RURAL DEVELOPMENT / DEPT. OF LAND RESOURCES, 2003)

Consolidated DPAP (Drought Prone Areas Programme), DDP (Desert Development Programme) and IWDP (Integrated Wastelands Development Programme) and aimed at empowering Panchayati Raj Institutions (PRIs) - Gram Panchayat and Zilla Parishad - financially and administratively to plan, implement and maintain watershed works, with the Gram Panchayat as the implementing body and the Gram Sabha approving works.

5.4 WARASA–JAN SAHBHAGITA VS HARIYALI (Answers IFoS 2024 | 2(A))

Basis	WARASA–Jan Sahbhagita	Hariyali
Nodal ministry	Agriculture (DAC)	Rural Development (Land Resources)
Programme	NWDPRA (rainfed areas)	DPAP + DDP + IWDP consolidated
Implementing body	PIA + Watershed Development Team	Gram Panchayat (PRI-led)
Community institution	Watershed Association / Committee	Gram Sabha / Gram Panchayat
Emphasis	Technical + participatory, dept-driven	Decentralised PRI empowerment
Year	2000	2003

5.5 COMMON GUIDELINES 2008 - SIX GUIDING PRINCIPLES (Answers IFoS 2022 | 1(A))

- **Equity & gender sensitivity** : Benefits to the poor, women and marginalised; ≥1 woman on each WDT.
- **Decentralization** : Empowered village/district institutions (DWDUs, Watershed Committees) with delegated authority and timely funds.
- **Facilitating agencies** : NGOs/specialist bodies mobilise and build community capacity, then withdraw.

- **Centrality of community participation** : Through SHGs, User Groups and Watershed Committees, accountable to the Gram Sabha; joint bank accounts for transparency.
- **Capacity building & technology input** : Training + GIS/remote-sensing-based scientific planning (≈5% of budget).
- **Monitoring, evaluation & learning** : Continuous, adaptive; online WPMIS.

5.6 PEOPLE'S PARTICIPATION (Answers IFoS 2017 | 1(A); WPM L25-26)

The community must be central to concept, planning, implementation and maintenance. The key tool is Participatory Rural Appraisal (PRA) - social & resource mapping, transect walks, and Indigenous Technical Knowledge (ITK). Participation ranges from passive and material-incentive up to functional, interactive and self-mobilised (the ideal). Women (primary users of water, fuel and fodder) and NGOs are integral. Illustrative successes: Ralegan Siddhi (Anna Hazare, Maharashtra) and the Rajiv Gandhi Mission / Jhabua (Madhya Pradesh), where ~80% of funds were community-managed.

5.7 MONITORING & EVALUATION (WPM L27-28)

Monitoring tracks physical and financial progress (quarterly/half-yearly reports, field visits, social audits, web-based WPMIS); evaluation - concurrent, mid-term and end-term (often external) - assesses whether water availability, productivity, livelihoods and ecology actually improved, following a 'before–during–after' approach.



6. WATER HARVESTING & MOISTURE CONSERVATION — IN-SITU

© Hornbill Classes
+91 78802-71423 Hornbillclasses@gmail.com

PREVIOUS YEAR QUESTIONS

- Compartmental bunding, intra-plot water harvesting, ridge-furrow & field bunding for in-situ conservation; enlist ex-situ methods.*** [IFoS 2025 | P1 Q3(b) | 10M]
- In-situ water-conservation practices for non-arable land with suitability and limitations.** [IFoS 2023 | P1 Q2(a) | 10M]
- In-situ moisture conservation methods for crop production under dryland areas.** [IFoS 2020 | P1 Q1(b) | 8M]

6.1 CONCEPT

Water harvesting is the collection and storage of rainwater/runoff for productive use and recharge. In in-situ harvesting, rain is conserved where it falls increasing infiltration and profile moisture best suited to arable and dryland crop areas.

6.2 IN-SITU METHODS ON ARABLE / DRYLAND (Answers IFoS 2025 | 3(B) & 2020 | 1(B))

- **Compartmental bunding** : The field is divided into small level compartments by low bunds so rain is impounded uniformly and soaks in.
- **Field bunding** : Earthen bunds around fields retain rain and runoff on the land.
- **Ridge-and-furrow / tied ridging** : Alternate ridges and furrows (cross-tied) store water in the furrows for the crop on the ridge.
- **Intra-plot water harvesting** : Micro-catchments within the plot direct runoff to a cropped strip.
- **Broad-bed-and-furrow, contour cultivation, dead/scoop furrows, mulching, conservation & off-season tillage, deep tillage** : Reduce runoff and hold moisture in the profile.

6.3 IN-SITU PRACTICES ON NON-ARABLE LAND (Answers IFoS 2023 | 2(A))

Contour trenches (continuous & staggered), contour stone walls, gradonis / bench-style trenches, crescent (semicircular) bunds, and saucer / V-ditch micro-catchments and catch-pits around tree pits — to support afforestation and pasture on non-cultivable slopes.

Suitability: degraded, sloping, non-arable lands. Limitations: labour-intensive, can breach under heavy rain, and need regular maintenance.

6.4 EX-SITU METHODS — ENLISTED (DETAILED IN §7)

Farm ponds, dug-out/embankment ponds, percolation tanks, check dams and nala bunds, sub-surface dams, recharge shafts, and rooftop rainwater harvesting.

7. WATER HARVESTING — EX-SITU STRUCTURES, RUNOFF INDUCEMENT, COMPONENTS & STEPS

PREVIOUS YEAR QUESTIONS

- Define water harvesting; components & sequential steps for runoff harvesting in dry regions; limitations.*** [IFoS 2017 | P1 Q2(c) | 10M]
- Runoff-inducing practices for increasing runoff for water harvesting.** [IFoS 2016 | P1 Q3(a) | 10M]
- Define farm pond; calculate the capacity of a farm pond using contours.** [OPSC 2024 | Q18 | 20M]

7.1 NEED & DEFINITION

India's average annual rainfall (~1,170 mm) is high but falls in short, high-intensity spells, so most drains away with little recharge - even Cherrapunji (>11,000 mm) faces drinking-water shortage because rain is not conserved. Ex-situ water harvesting stores runoff away from where it falls, for direct use or recharge.

7.2 EX-SITU STRUCTURES (WPM L19–20, L13–14)

- **Farm ponds** : Dug-out (flat land) or embankment type; store runoff for supplemental irrigation.
- **Percolation tanks** : On wasteland/small drains to impound runoff and recharge groundwater.
- **Tanks (bund <12 m)** in networks: isolated, inter-connected, or in series.
- **Check dams / nala bunds** across drainage lines; recharge structures - recharge basins, furrows-and-ditches, regulated stream channels, spreading galleries (L13).
- **Rooftop rainwater harvesting (RRCS)** with catchment–gutter–filter–storage tank; plastic (LDPE)-lined ponds to cut seepage.

7.3 COMPONENTS OF A RUNOFF WATER-HARVESTING SYSTEM (Answers IFoS 2017 | 2(C))

(a) Catchment (runoff-producing area)
(b) Conveyance (channels/drains)
(c) Storage or recharge structure (pond/tank/recharge shaft)
(d) Application/distribution to the field.

7.4 SEQUENTIAL STEPS

Site & catchment selection → estimate runoff yield → design conveyance → design storage/recharge structure → distribution to the command area.

7.5 RUNOFF-INDUCING PRACTICES (Answers IFoS 2016 | 3(A))

To increase runoff from the catchment for harvesting - smoothing and compacting the catchment surface, clearing vegetation, and surface treatment to reduce permeability: sodium-salt (dispersant) treatment, bitumen/asphalt, plastic film, or chemical sealants.

7.6 LIMITATIONS

Dependent on uncertain rainfall; seepage and evaporation losses; siltation of storage; land and cost for the structure; and regular maintenance.

∑ Farm-pond / tank capacity by the contour (prismoidal) method

With horizontal contour areas A_0, A_1, A_2 … A_n at uniform contour interval h:

Prismoidal : $V = (h/3)[A_0 + A_n + 4(A_1+A_3+\ldots) + 2(A_2+A_4+\ldots)]$

Average-end-area (trapezoidal): $V = h[(A_0+A_n)/2 + A_1 + A_2 + \ldots + A_{n-1}]$

☞ **Farm-pond capacity from contour areas (OPSC-type)**

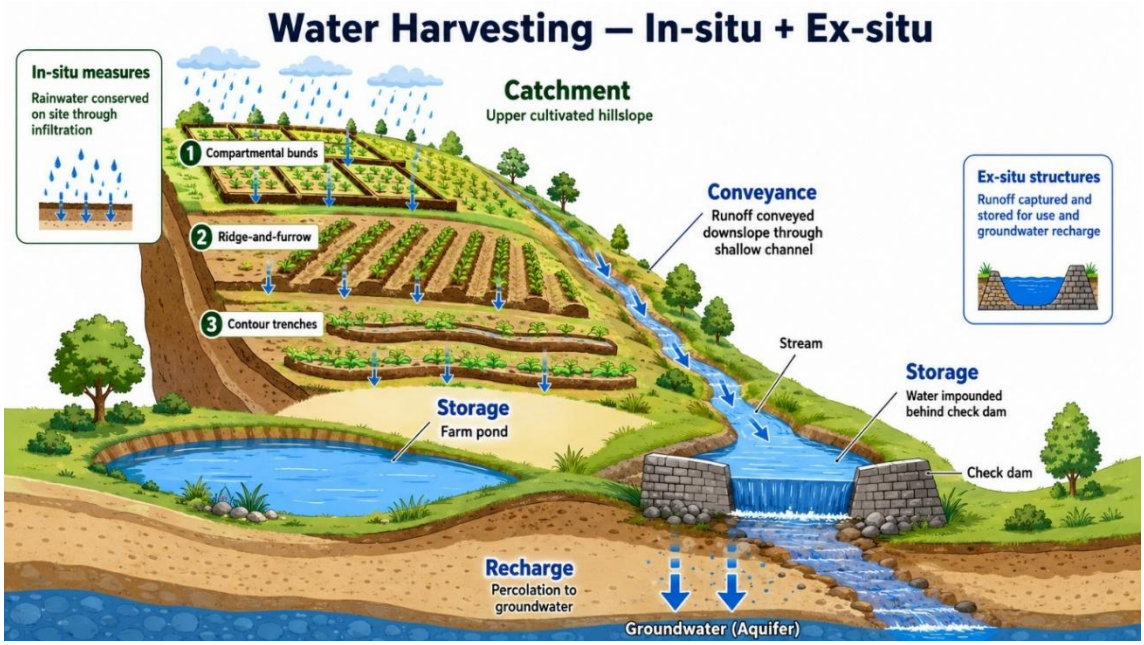
A farm pond has contour areas at 1 m interval: A_0=100, A_1=160, A_2=240, A_3=340 m². Find its capacity (prismoidal).

$V = (1/3)[A_0 + A_3 + 4A_1 + 2A_2] = (1/3)[100 + 340 + 4(160) + 2(240)]$

$= (1/3)[100 + 340 + 640 + 480] = (1/3)(1560) = 520$ m³.

© Hornbill Classes
+91 78802-71423 Hornbillclasses@gmail.com

In practice, in-situ and ex-situ measures are sequenced together along a ridge-to-valley hillslope : In-situ works on the upper arable slope (compartmental bunds, ridge-and-furrow, contour trenches) first conserve rainfall in the soil profile and cut peak runoff; the surplus that still runs off is conveyed downslope and intercepted by ex-situ structures - a farm pond or check dam - for storage, supplemental irrigation, or recharge to groundwater. This catchment → conveyance → storage → recharge chain (§7.3) is the combined sequence Figure 4 depicts.



8. FLOOD ROUTING — CONCEPT, ELEMENTS & RESERVOIR (STORAGE) ROUTING

PREVIOUS YEAR QUESTIONS

- Define flood routing. Discuss the basic elements of flood routing.** [IFoS 2018 | P1 Q3(c) | 10M]
- Explain flood routing and their types; write their inflow–outflow relationship.** [OPSC | Forest 2023 | 3(a)]

8.1 DEFINITION

Flood routing is the technique of determining the flood hydrograph at a section of a river using the flood-flow data at one or more upstream sections - *i.e.* tracking how a flood wave changes as it moves through a reservoir or channel.

8.2 TYPES

- **Reservoir routing** : Effect of a flood wave entering a reservoir; using storage–elevation and outflow–elevation relations, it predicts reservoir level and outflow with time (for spillway/outlet design and reservoir sizing).
- **Channel routing** : change in shape of the hydrograph as it travels down a reach; gives flood-peak attenuation and lag (for flood forecasting and protection).

8.3 USES

Flood forecasting, flood protection, reservoir design and spillway design.

8.4 BASIC ELEMENTS / GOVERNING EQUATIONS

The primary equation is

continuity — inflow − outflow = rate of change of storage: $I - Q$

$= dS/dt$, or over Δt: $\frac{1}{2}(I_1+I_2)\Delta t - \frac{1}{2}(Q_1+Q_2)\Delta t = S_2 - S_1$.

The full unsteady-flow description adds the equation of motion; together the continuity + momentum equations are the **St. Venant equations.** Hydrologic routing uses only continuity + a storage function; hydraulic routing solves both St. Venant equations. Δt must be shorter than the flood-wave transit time.

8.5 RESERVOIR ROUTING — MODIFIED PUL'S METHOD

Rearranging continuity to group storage and outflow, only two curves are needed the S-curve and the $(2S/\Delta t + Q)$-curve. Steps:

(1) Get average inflow over Δt
(2) Read $(2S/\Delta t - Q)$ for the initial outflow
(3) Add average inflow to obtain $(2S/\Delta t + Q)_2$
(4) Read Q_2 from the curve;
(5) Repeat. The routed outflow shows peak attenuation and time lag relative to inflow.

9. MUSKINGUM CHANNEL ROUTING - PREMISE, K & X ESTIMATION + NUMERICAL

Muskingum channel routing is a storage-based (hydrologic) method for tracking how a flood wave attenuates and lags as it travels down a channel reach. Reach storage is split into prism storage (a function of outflow Q) and wedge storage (a function of inflow I); combined with continuity, this yields a routing equation that steps the outflow hydrograph forward once the reach parameters **K** (storage-time constant) and **x** (weighting factor) are known.

PREVIOUS YEAR QUESTIONS

- Basic premise of the Muskingum method; procedure to estimate coefficients K and x for a stream reach. ** [IFoS 2024 | P1 Q4(c) | 15M]
- Explain the channel routing model (Muskingum Equation).** [OPSC | Forest 2023 | 3(b)]

9.1 PRISM & WEDGE STORAGE

Total storage in a reach = prism storage (volume under a plane parallel to the bed at the downstream depth, a function of outflow **Q**) + wedge storage (between the actual water surface and the prism top, a function of inflow **I**; positive on a rising flood, negative on a falling flood).

9.2 BASIC PREMISE (ANSWERS IFOS 2024·4(C))

Muskingum assumes storage is a linear function of weighted inflow and outflow:

$S = K[xI + (1 - x)Q]$,

where

x = weighting factor ($0 \le x \le 0.5$; natural channels 0–0.3)

and **K** = storage-time constant (dimension of time), ≈ the travel time of the flood wave through the reach.

© Hornbill Classes
+91 78802-71423 Hornbillclasses@gmail.com

When x = 0 the reach behaves as a linear reservoir (S = KQ).

9.3 ESTIMATION OF K AND X (ANSWERS IFOS 2024·4(C))

From an observed inflow and outflow hydrograph for the reach:

(1) using continuity, compute incremental storage **ΔS** each interval and cumulate to get S vs t;

(2) assume a trial value of x; compute **[xI + (1 − x)Q]**;

(3) plot S against **[xI + (1 − x)Q]** - the correct x gives a plot closest to a straight line (a wrong x gives a wide loop);

(4) the inverse slope of that line = **K.**

∑ Muskingum routing equation & coefficients

Storage change: $S_2 - S_1 = K[x(I_2 - I_1) + (1-x)(Q_2 - Q_1)]$.

Continuity: $\frac{1}{2}(I_1+I_2)\,\Delta t - \frac{1}{2}(Q_1+Q_2)\,\Delta t = S_2 - S_1$.

Eliminating storage: $Q_2 = C_0 I_2 + C_1 I_1 + C_2 Q_1$, where $(D = K - Kx + 0.5\Delta t)$:

$C_0 = (0.5\Delta t - Kx)/D$; $C_1 = (0.5\Delta t + Kx)/D$; $C_2 = (K - Kx - 0.5\Delta t)/D$; $C_0 + C_1 + C_2 = 1$.

Routing interval chosen so that $K > \Delta t > 2Kx$.

☞ **Muskingum routing (Watershed Hydrology Example 1)**

Route the flood below through a reach with K = 8 h, x = 0.25, Δt = 4 h; initial outflow = 8 m³/s.

Time (h): 0, 4, 8, 12, 16, 20, 24, 28 Inflow (m³/s): 8, 16, 30, 30, 25, 20, 15, 10

Coefficients: D = 8 − 2 + 2 = 8 → $C_0 = 0$; $C_1 = 0.5$; $C_2 = 0.5$ (Σ = 1 ✓). So $Q_2 = 0.5\, I_1 + 0.5\, Q_1$.

t (h)	Inflow I	Q routed
0	8	8.0
4	16	8.0
8	30	12.0
12	30	21.0
16	25	25.5
20	20	25.25
24	15	22.6
28	10	18.8

Peak inflow 30 m³/s → peak outflow ≈ 25.5 m³/s ⇒ attenuation ≈ 4.5 m³/s, with the peak lagged — exactly what channel routing captures.

10. FLOOD CONTROL — STORAGE & DETENTION RESERVOIRS & WATERSHED FLOOD MEASURES

PREVIOUS YEAR QUESTIONS

- Storage reservoirs and detention reservoirs adopted for control of floods.*** [IFoS 2024 | P1 Q1(d) | 8M]
- What is a flood? Describe various flood-control measures in a watershed.**

[UKPSC RFO 2012 | Q3(ii) | 10M]

10.1 FLOOD - DEFINITION & SEVERITY

Per INCID (Indian National Committee on Irrigation and Drainage), a flood is a relatively high flow/stage in a river that overflows and inundates land not normally under water; caused by inadequate channel capacity, aggravated by bed silting, landslides, synchronization of tributary floods and tidal retardation. Severity is judged by depth, duration, velocity, rate of rise, frequency and seasonality of flow.

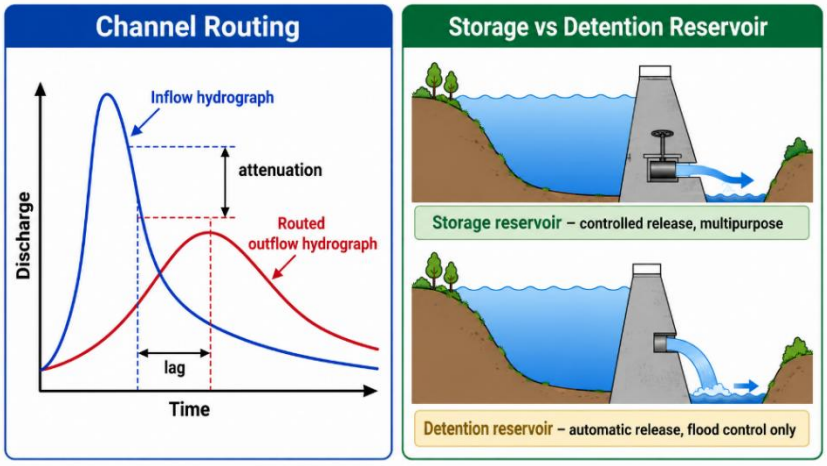
10.2 STORAGE VS DETENTION RESERVOIRS (Answers IFoS 2024 | 1(D))

Basis	Storage (conservation) reservoir	Detention reservoir
Outlets	Gated / controlled	Ungated, fixed-capacity (spillway + sluice)
Operation	Stores flood water; released in a regulated manner	Automatically detains & releases at a safe, non-damaging rate
Purpose	Multipurpose — flood moderation + irrigation/power/supply	Flood control only (single purpose)
Size / retention	Large; long-term storage	Smaller; temporary detention of the peak

Both cut the flood peak by holding part of the flood volume and releasing it slowly the reduction rises with storage capacity.

10.3 STRUCTURAL FLOOD-CONTROL MEASURES

Embankments, flood walls & sea walls; dams & reservoirs; natural detention basins; channel improvement (deepening/widening for more capacity); drainage improvement; and diversion of flood waters.



10.4 NON-STRUCTURAL MEASURES

Floodplain zoning, flood forecasting & warning, flood proofing, and emergency preparedness/response.

10.5 FLOOD CONTROL WITHIN A WATERSHED (Answers UKPSC 2012)

Ridge-to-valley treatment afforestation and contour bunding/trenching on the upper catchment to cut runoff at source; check dams, nala bunds and percolation tanks in the drainage line; and detention storage all reducing the peak runoff reaching downstream.

11. DROUGHT MANAGEMENT

PREVIOUS YEAR QUESTIONS

- Define hydrological drought. Write its components and effects. List measures to lessen drought effects.*** [IFoS 2018 | P1 Q1(d) | 8M]

© Hornbill Classes
+91 78802-71423 Hornbillclasses@gmail.com

11.1 WHAT IS DROUGHT

Drought is a period of unusually dry weather, persisting long enough to cause environmental or economic harm; it originates from a deficiency of precipitation over an extended period (a season or more) relative to the long-term balance between precipitation and evapotranspiration for that area. It develops gradually and is region-specific.

11.2 TYPES OF DROUGHT (FOUR DISCIPLINARY DEFINITIONS)

- **Meteorological** : Degree and duration of dryness (rainfall below a threshold vs 'normal').
- **Agricultural** : Soil-moisture deficit affecting crops, linking rainfall shortfall and the gap between actual and potential evapotranspiration at sensitive crop stages.
- **Hydrological** : Deficiency in surface and subsurface water supplies (streamflow, reservoir/lake levels, groundwater), lagging behind the above.
- **Socio-economic** : When demand for economic goods (water, food, hydropower) exceeds supply owing to a weather-related shortfall.

11.3 HYDROLOGICAL DROUGHT - COMPONENTS & EFFECTS (Answers IFoS 2018 | 1(D))

Components : reduced streamflow/runoff, depleted reservoir and lake storage, and a lowered groundwater table. **Effects** : shortage of water for irrigation, domestic and industrial supply; reduced hydropower; failure of wells and surface sources; ecological stress; and socio-economic distress. **Monitoring indices** : Percent-of-Normal, SPI (Standardized Precipitation Index), PDSI (Palmer Drought Severity Index), Crop Moisture Index, Surface Water Supply Index, Reclamation Drought Index, Deciles.

11.4 DROUGHT-MANAGEMENT MEASURES (WH L31)

Area-specific: water conservation and evaporation retardation (cetyl/stearyl/fatty-alcohol films cut field evaporation ~40%); reduction of conveyance losses (canal lining, seepage 35–45%); equitable rotational distribution (warabandi) and system maintenance; better irrigation practice (land levelling); conjunctive use of surface and groundwater; watershed development (check dams, nala bunding, contour bunds, gully plugging, percolation tanks, RWH); creation of large storages (more drought-proof than many small tanks; ~80% of river flow is in the four monsoon months); and contingency crop planning (drought-tolerant crops, dryland practices, §6).

12. LAND DEVELOPMENT I — LAND GRADING / LEVELLING: FACTORS, SURVEY & PLANE METHOD

PREVIOUS YEAR QUESTIONS

- Explain the criteria for land levelling design.*** [IFoS 2024 | P1 Q3(a) | 10M]
- In the plane method: (i) centroid of the field, (ii) slope of the plane of best fit, (iii) formation levels, cuts and fills.*** [IFoS 2022 | P1 Q3(b) | 15M]
- Factors affecting land grading; how survey is carried out; methods for earthwork (earthwork → §13).** [IFoS 2018 | P1 Q4(b) | 10M]
- Land shaping concepts, purpose and applicability in a watershed.** [IFoS 2017 | P1 Q1(b) | 8M]
- Laser land levelling; land-grading design by plane method.** [OPSC 2017 | 1(a); UKPSC 2012 | 3(iii)]

12.1 LAND DEVELOPMENT / LAND SHAPING — CONCEPT & PURPOSE (Answers IFoS 2017 | 1(B))

Land shaping / development modifies the land surface (levelling, grading, smoothing) to control water movement, enable efficient and uniform irrigation, reduce erosion, improve drainage and ease machinery operation — an essential pre-treatment on arable land within a watershed.

12.2 TERMS

Land levelling = reshaping the surface to a planned grade; land grading = providing a designed uniform slope for irrigation/drainage; land smoothing = a final light operation removing minor irregularities.

12.3 FACTORS AFFECTING LAND GRADING (Answers IFoS 2018 | 4(B))

Existing topography/slope; soil depth and type (limits the depth of cut so as not to expose infertile subsoil); climate/rainfall; method of irrigation; crops to be grown; drainage requirement; cut–fill balance; and cost.

12.4 CRITERIA FOR LAND LEVELLING DESIGN (Answers IFoS 2024 | 3(A))

The design slope must be safe against erosion yet adequate for irrigation and drainage; earthwork must be minimum; cut and fill should be balanced (cut ≈ 1.2–1.5 × fill to allow for soil shrinkage/compaction after filling); the fertile topsoil should be preserved (limit depth of cut); and the finished grade should be as uniform as the ground allows.

12.5 SURVEY FOR LAND GRADING (Answers IFoS 2018 | 4(B))

A grid (staking) survey: the field is divided into a grid (e.g. 20–30 m squares) pegged at each node; a benchmark is fixed and the ground reduced level (RL) is levelled and recorded at every grid point. These grid elevations are the input to the design methods.

12.6 PLANE METHOD OF LAND LEVELLING DESIGN (Answers IFoS 2022 | 3(B))

(i) **Centroid of the field :** For a regular grid the centroid is the point whose coordinates are the mean of the grid coordinates; the plane of best fit passes through it, and its elevation equals the mean of all grid elevations, $\bar{h}$.

(ii) **Slope of the plane of best fit (least squares) :** $S_x = \Sigma[(x-\bar{x})(h-\bar{h})] / \Sigma(x-\bar{x})^2$ and $S_y = \Sigma[(y-\bar{y})(h-\bar{h})] / \Sigma(y-\bar{y})^2$ — the down-field and cross slopes that best fit the ground.

(iii) **Formation levels, cuts and fills :** formation (design) RL at any point = $\bar{h} + S_x(x-\bar{x}) + S_y(y-\bar{y})$ using the adopted design slopes; cut/fill at a point = ground RL − formation RL (positive = cut, negative = fill).

12.7 LASER LAND LEVELLING (State PYQ)

Equipment : a rotating laser transmitter (sets a reference plane), a receiver on a mast fixed to a drag scraper, a control box and hydraulic valves. As the tractor-drawn scraper moves, the receiver senses its position relative to the laser plane and the control box automatically raises/lowers the bucket to cut or fill to grade - achieving ±1–2 cm precision. **Benefits** : uniform grade, 20–30% irrigation-water saving, better crop stand and yield, and time saving over conventional levelling.

∑ Plane of best fit (least-squares) — working formulas

Centroid elevation: $\bar{h} = (\Sigma h)/n$.

Down-field slope: $S_x = \Sigma[(x-\bar{x})(h-\bar{h})] / \Sigma(x-\bar{x})^2$.

Cross slope: $S_y = \Sigma[(y-\bar{y})(h-\bar{h})] / \Sigma(y-\bar{y})^2$.

Formation RL at (x,y): $h_f = \bar{h} + S_x(x-\bar{x}) + S_y(y-\bar{y})$.

Cut/Fill = ground RL − formation RL.

© Hornbill Classes
+91 78802-71423 Hornbillclasses@gmail.com

☞ **Plane method — formation level & cut/fill (textbook-type)**

A field is levelled to a single down-field slope. Four grid points along a line at 30 m spacing read RLs 100.60, 100.30, 100.10, 99.80 m. Design to the plane of best fit (cross slope = 0).

x (from first peg) = 0, 30, 60, 90 m → $\bar{x}$ = 45 m;

$\bar{h}$ = (100.60+100.30+100.10+99.80)/4 = 100.20 m.

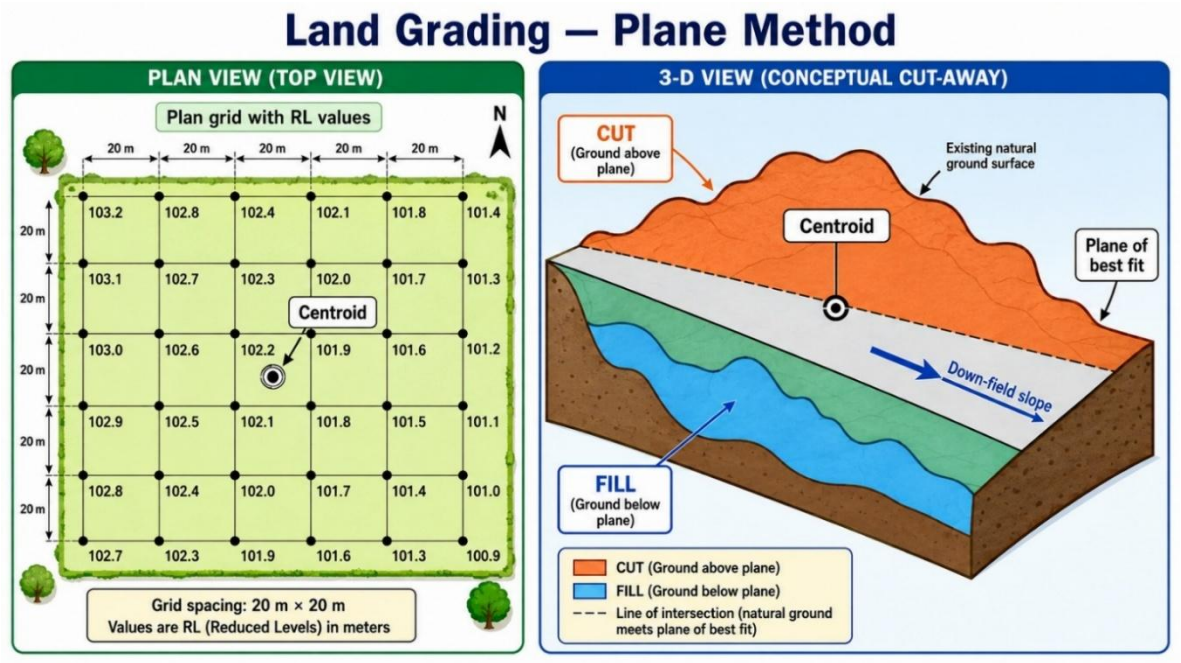
$\Sigma(x-\bar{x})(h-\bar{h})$: (−45)(0.40)+(−15)(0.10)+(15)(−0.10)+(45)(−0.40) = −18−1.5−1.5−18 = −39.

$\Sigma(x-\bar{x})^2 = 45^2+15^2+15^2+45^2 = 2025+225+225+2025 = 4500$.

Sx = −39/4500 = −0.00867 (i.e. a fall of 0.87 m per 100 m).

Formation RL at peg 1 (x=0): 100.20 + (−0.00867)(0−45) = 100.20 + 0.39 = 100.59 → cut = 100.60 − 100.59 = 0.01 m.

At peg 4 (x=90): 100.20 + (−0.00867)(45) = 100.20 − 0.39 = 99.81 → fill = 99.80 − 99.81 = −0.01 m. (Cut ≈ fill, balanced ✓)



13. LAND DEVELOPMENT II - EARTHWORK COMPUTATION, COSTING & MACHINERY

PREVIOUS YEAR QUESTIONS

- Methods for computation of earthwork; machinery/equipment used for land grading.*** [IFoS 2019 | P1 Q4(a) | 10M]
- Different methods of calculating earth and soil volumes.** [IFoS 2017 | P1 Q1(c) | 8M]
- Volume of earthwork for a trapezoidal canal by trapezoidal and prismoidal formulae.** [OPSC 2024 | Q2 | 15M]

13.1 METHODS OF EARTHWORK COMPUTATION (Answers IFoS 2019 | 4(A) & 2017 | 1(C))

- **Cross-section methods** (roads/canals) : Mid-section, average end-area (trapezoidal), and prismoidal formulae.

- **Grid / spot-level methods** (land grading) : Four-point method, summation method, prismoidal method, and plan-inspection method.

13.2 FOUR-POINT (GRID) METHOD

For each grid square,

cut (or fill) volume = (grid area / 4) × Σ(depth of cut, or fill, at its four corners).

Summing over all squares gives total cut and total fill separately.

13.3 SUMMATION METHOD

Total volume = grid-cell area × (Σ of all cuts, or fills, at the grid points) — a quick approximation treating each point's depth as acting over its own cell.

13.4 CUT–FILL RATIO & COSTING

Design so that total cut ≈ 1.2–1.5 × total fill (fill soil compacts/shrinks);

earthwork cost = volume moved × unit rate,

adjusted for haul distance and lift. Balanced cut/fill avoids costly borrow or spoil.

13.5 MACHINERY FOR LAND GRADING (Answers IFoS 2019 | 4(A))

Bulldozer (cutting/pushing over short hauls); land plane / land leveler (final smoothing to grade); scraper / carryall / buck scraper (cut, haul and spread over longer distances); motor grader (fine grading); tractor-drawn leveler; and the laser land leveler (automatic precision grading, §12.7).

∑ Earthwork formulae

Four-point method (per grid square of area A): $V = (A/4)\,\Sigma$(corner depths).

Average end-area (trapezoidal): $V = L[(A_1+A_n)/2 + A_2+\ldots+A_{n-1}]$.

Prismoidal: $V = (L/3)[A_1 + A_n + 4$(even sections) $+ 2$(odd interior sections)$]$.

Trapezoidal-canal section area at depth d (bottom b, side slope s:1): $A = (b + s\cdot d)\cdot d$.

☞ **Trapezoidal-canal earthwork — trapezoidal vs prismoidal (OPSC 2024)**

Canal: bottom b = 10 m, side slopes 1.5H:1V; ground level transverse; bed depths at 40 m intervals: 0.90, 1.25, 2.15, 2.50, 1.85, 1.35, 0.85 m. Area A = (10 + 1.5d)d.

Areas (m²) : 10.215, 14.844, 28.434, 34.375, 23.634, 16.234, 9.584. (L = 40 m, 7 sections.)

Trapezoidal : V = 40[(10.215+9.584)/2 + 14.844+28.434+34.375+23.634+16.234] = 40[9.900 + 117.521] = 5096.8 m³.

Prismoidal : V = (40/3)[10.215+9.584 + 4(14.844+34.375+16.234) + 2(28.434+23.634)] = (40/3)[19.799 + 261.812 + 104.136] = 5143.3 m³.

☞ **Reduced levels by the HI method — grid levelling (surveying for land grading)**

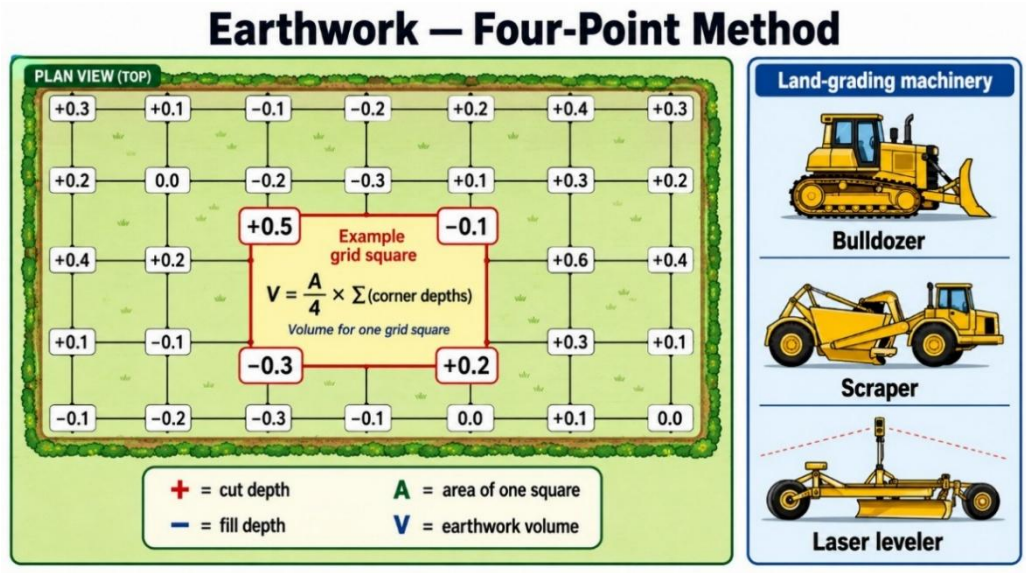
Height-of-Instrument method: **HI = RL of point + Back Sight; RL of next point = HI – (Inter/Fore Sight)**.

e.g. BM RL(A) = 245.000, BS = 2.375 → HI = 247.375; RL(B) = HI − IS(0.615) = 246.760;

at each change point take a fresh BS for a new HI.

Arithmetic check: ΣBS − ΣFS = Last RL − First RL.

© Hornbill Classes
+91 78802-71423 Hornbillclasses@gmail.com



14. WIND EROSION PROCESS & SAND-DUNE FIXATION

PREVIOUS YEAR QUESTIONS

- Types of soil movement due to wind erosion; how particles of various sizes move.** [IFoS 2018 | P1 Q4(d) | 10M]
- Methods of reducing surface wind velocities in wind-erosion control.** [IFoS 2020 | P1 Q2(a) | 10M]
- What are sand dunes? Describe the procedure for fixing sand dunes.** [IFoS 2022 | P1 Q1(b) | 8M]

14.1 WIND EROSION PROCESS (WPM L16)

Wind erosion involves detachment, transport and deposition of soil particles by wind, prominent in arid/semi-arid regions with loose, dry, bare, fine soils and high wind velocity.

14.2 TYPES OF SOIL MOVEMENT (Answers IFoS 2018 | 4(D))

- **Saltation** : Particles 0.1–0.5 mm bounce/skip along the surface in a series of jumps; the dominant mode (≈ 50–75% of total movement) and the trigger for the other two.
- **Suspension** : Fine particles < 0.1 mm are lifted and carried high and far in the air stream (dust storms).
- **Surface creep** : Coarse particles > 0.5 mm roll and slide along the surface, pushed by saltating grains (≈ 5–25%).

14.3 REDUCING SURFACE WIND VELOCITY (Answers IFoS 2020 | 2(A))

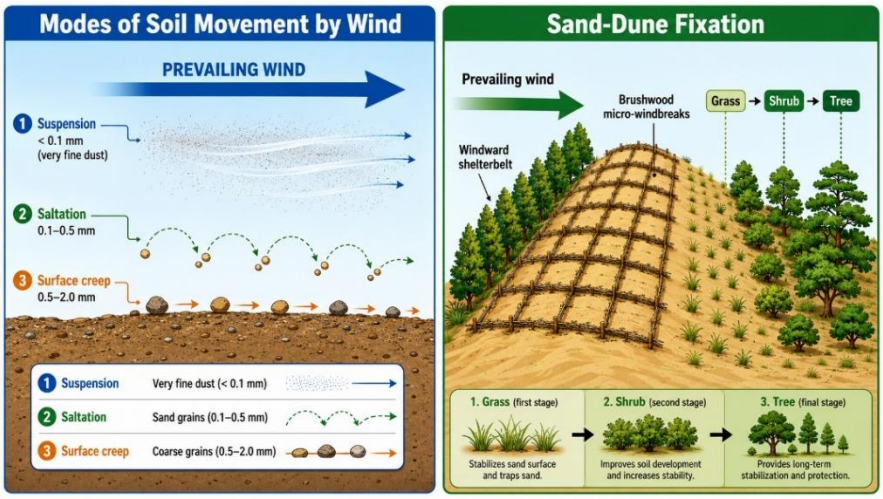
Establish shelterbelts and windbreaks across the prevailing wind; maintain a vegetative cover / cover crops; strip cropping across the wind; tillage that produces a cloddy, ridged, rough surface; stubble/residue mulching; and keeping the soil moist and consolidated. These raise surface roughness and lower the wind velocity at ground level below the threshold that moves soil.

14.4 SHELTERBELTS & WINDBREAKS — DESIGN FACTORS

Height (protection extends ~10–20 times the height on the leeward side); density/permeability (~40–50% permeable is most effective - a solid barrier causes turbulence); orientation perpendicular to the prevailing wind; adequate length and number of rows (shrubs + tall trees); and correct spacing between belts.

14.5 SAND DUNES & THEIR FIXATION (Answers IFoS 2022 | 1(B))

Sand dunes are mounds/ridges of wind-deposited sand formed in arid regions where saltating sand accumulates around an obstruction; live (mobile) dunes bury cropland, roads and canals. Types include barchan (crescentic), transverse, longitudinal (seif) and parabolic. Fixation procedure:



- Protect the dune from grazing and traffic (fencing) to stop fresh disturbance.
- Erect micro-windbreaks — brushwood/checkerboard fences (parallel & perpendicular) on the dune to break wind velocity and trap sand.
- Mulch / spray the surface with a stabiliser (bitumen emulsion) to hold the sand temporarily.
- Establish vegetation in stages — hardy drought-resistant grasses first, then shrubs, then trees (Prosopis, Acacia, Calligonum, Tamarix) in the sheltered pockets for permanent cover.
- Raise shelterbelts on the windward side for long-term protection.

QUICK-REVISION FORMULA SHEET

Topic	Key formula / value
Bifurcation ratio	Rb = Nw / N(w+1) (3–5)
Drainage density	Dd = L / A
Length of overland flow	L_o = 1 / (2 Dd)
Form / shape factor	A/L^2 ; L^2/A
Elongation / compactness	1.128√A/L ; 0.2821 P/√A
Muskingum storage	S = K[xI + (1−x)Q], 0 ≤ x ≤ 0.5
Muskingum routing	$Q_2 = C_0I_2 + C_1I_1 + C_2Q_1$; $C_0+C_1+C_2 = 1$
Routing coefficients	$C_0=(0.5\Delta t-Kx)/D$, $C_1=(0.5\Delta t+Kx)/D$, $C_2=(K-Kx-0.5\Delta t)/D$; $D=K-Kx+0.5\Delta t$
Routing interval	$K > \Delta t > 2Kx$
Continuity (routing)	I − Q = dS/dt
Prismoidal volume	$V = (L/3)[A_1+A_n + 4(\text{even}) + 2(\text{odd interior})]$
Average end-area	$V = L[(A_1+A_n)/2 + A_2+\ldots+A_{n-1}]$
Four-point earthwork	V = (A/4) Σ(corner cut or fill depths)
Trapezoidal-canal area	A = (b + s·d)·d
Plane of best fit — slope	$Sx = \Sigma[(x-\bar{x})(h-\bar{h})]/\Sigma(x-\bar{x})^2$
Formation level	$h_f = \bar{h} + Sx(x-\bar{x}) + Sy(y-\bar{y})$
Cut / fill	= ground RL − formation RL ; design cut ≈ 1.2–1.5 × fill
Farm-pond capacity	prismoidal / average-end-area of contour areas

© Hornbill Classes
+91 78802-71423 Hornbillclasses@gmail.com

CHAPTER

5

AERIAL PHOTOGRAPHY & REMOTE SENSING

EMR · Resolutions · Spectral Signatures · Satellites & Orbits · Photogrammetry · Photo-interpretation · Digital Image Processing · DEM · RS Applications

OFFICIAL SYLLABUS — *Chapter 5 scope*

Aerial photography — photointerpretation, stereoscopy, vertical exaggeration. Remote-sensing classification by platform, energy source, EM spectrum and bands. Active vs passive RS; geostationary and polar sun-synchronous satellites; satellite orbital characteristics. EMR interaction with atmosphere and Earth's surface; atmospheric windows; absorption and scattering. Spectral reflectance curves for soil, water and vegetation. Spatial, spectral and temporal resolution. Digital image processing — restoration, geometric and radiometric correction, classification, principal component analysis, false-colour composites, ground-truthing. Applications: agriculture, forestry, water resources, land cover/use mapping, archaeology, forest cover mapping, crop-water-stress monitoring, DEMs.

Chapter Outline

1 Introduction To Remote Sensing
2 Classification Of Remote Sensing
3 Electromagnetic Radiation & Energy Interactions
4 Spectral Reflectance & Signatures
5 Resolution In Remote Sensing
6 Satellites, Orbits & Platforms
7 Aerial Photography
8 Photogrammetry & Stereoscopy
9 Photo / Image Interpretation
10 Digital Image Processing (Dip)
11 Digital Elevation Models (Dem)
12 Applications Of Remote Sensing
13 Key Definitions (Glossary)

1. INTRODUCTION TO REMOTE SENSING

Remote sensing is the science (and art) of acquiring information about an object, area or phenomenon through the analysis of data acquired by a device that is **not in physical contact** with the object under investigation. The data are recorded by sensors such as cameras, scanners, radiometers, radar and LiDAR, carried on platforms like aircraft, balloons, drones and satellites.

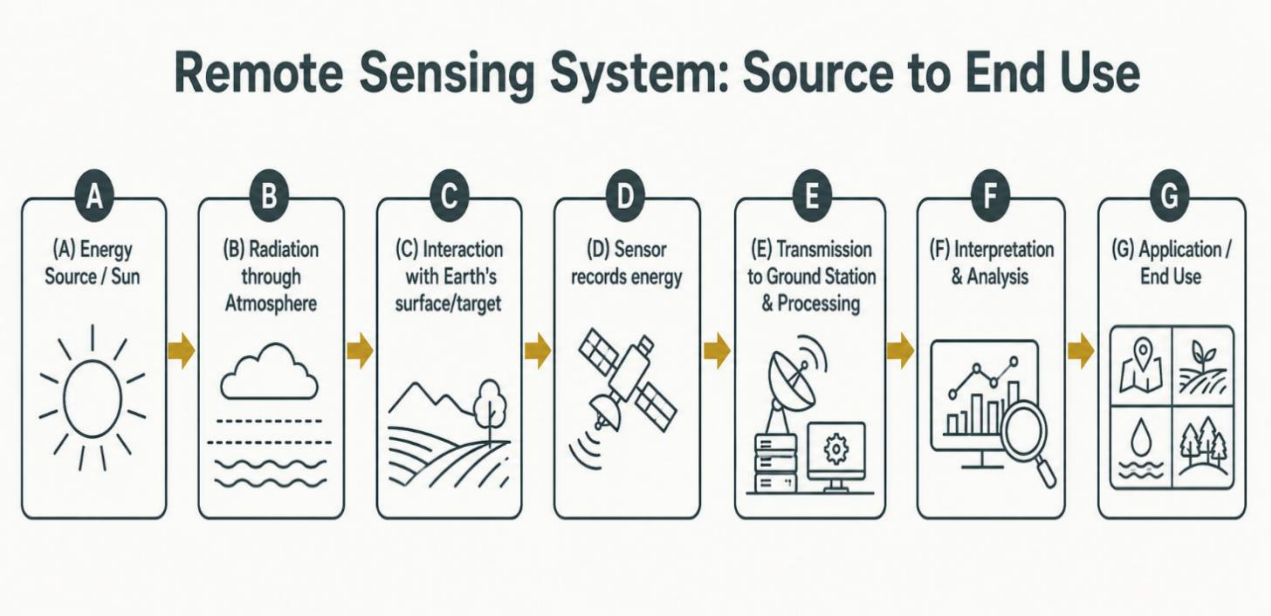
The underlying principle is that **every object reflects, emits or scatters electromagnetic energy** in a characteristic manner depending on its physical and chemical properties. By recording and interpreting this energy, the nature of the object can be identified without touching it.

1.1 STAGES / PROCESS OF REMOTE SENSING (SOURCE TO END USE)

PYQ *IFoS 2018 1(e): Define remote sensing. Stages in RS data acquisition & processing; system diagram source→ end use. | UK·PSC 2015: stages of RS.*

A complete remote-sensing system involves the following sequential stages:

1. **Energy source / illumination (A) :** An energy source that illuminates or provides electromagnetic energy to the target (the Sun for passive RS; the sensor's own source for active RS).
2. **Radiation and the atmosphere (B) :** As the energy travels from source to target, it interacts with the atmosphere (scattering, absorption); a second interaction occurs on its way back to the sensor.
3. **Interaction with the target (C) :** Energy interacts with the Earth's surface — it is reflected, absorbed and/or transmitted depending on the properties of both the object and the radiation.
4. **Recording of energy by the sensor (D) :** The sensor collects and records the reflected or emitted electromagnetic radiation.
5. **Transmission, reception and processing (E) :** The recorded energy is transmitted to a ground receiving station and processed into an image (analogue or digital).
6. **Interpretation and analysis (F) :** The image is interpreted visually and/or digitally to extract information about the target.
7. **Application (G) :** The extracted information is applied to solve a particular problem (resource management, mapping, monitoring) — the end use.



© Hornbill Classes
+91 78802-71423
Hornbillclasses@gmail.com

1.2 ESSENTIAL COMPONENTS OF REMOTE SENSING

PYQ *HP·PSC 2021 2(c): essential components of remote sensing.*

The functioning of a remote-sensing system depends on the following essential components:

- **Energy source** : Supplies electromagnetic radiation to the target (Sun / artificial source).
- **Atmosphere / propagation medium** : The path through which energy travels; it modifies radiation via scattering and absorption.
- **Target / Earth's surface features** : Soil, water, vegetation, rocks etc., each with a unique spectral response.
- **Sensor** : Device that detects and records electromagnetic radiation (camera, scanner, radiometer, radar).
- **Platform** : Vehicle carrying the sensor (ground, airborne, spaceborne).
- **Data reception, transmission and processing system** : Ground stations that receive and convert raw data into usable imagery.
- **Data product and interpretation** : Analysis and conversion of imagery into thematic information.
- **End user / application** : The agency or purpose for which information is generated.

1.3 ADVANTAGES OF REMOTE SENSING

PYQ *Arunachal PSC 2015: RS advantageous vs ground survey. | (also legacy IFoS).*

- Provides a **synoptic (bird's-eye) view** of a large area as a whole, enabling regional analysis.
- Allows **repetitive (multi-temporal) coverage**, essential for change detection and monitoring.
- Can give a **3-D (stereoscopic) view** of terrain and objects when used with a stereoscope.
- Enables data collection from **remote and inaccessible areas** (high mountains, dense forests, hostile terrain) quickly and safely.
- **Multi-spectral capability** records information beyond the visible range (infrared, thermal, microwave), revealing features invisible to the eye — e.g., early detection of insect/disease attack and crop stress.
- **Time- and cost-effective** for large areas; faster and more accurate than conventional ground survey.
- Provides data in **digital form** suitable for GIS integration and computer analysis.

1.4 CONVENTIONAL SURVEY VS REMOTE SENSING — MERITS & DEMERITS

PYQ *OPSC Forest 2019, 2023: merits & demerits of conventional vs remote-sensing techniques.*

Basis	Conventional (Ground) Survey	Remote Sensing
Coverage	Small area at a time; point/transect data	Large synoptic coverage in a single frame
Time & cost	Slow, labour-intensive, costly for large areas	Rapid; cost-effective per unit area
Accessibility	Difficult/risky in inaccessible terrain	Easily covers inaccessible & hostile areas
Repetitivity	Repeat survey is costly and slow	Frequent repetitive coverage (monitoring)
Spectral range	Limited to visible observation	Visible + IR + thermal + microwave
Accuracy (local detail)	High local/ground accuracy & detail	Depends on resolution; needs ground truthing
Data form	Mostly analogue / field notes	Digital — GIS-ready
Limitation	Tedious, not suited to large-scale mapping	Needs calibration, atmospheric correction & ground verification; high initial system cost

2. CLASSIFICATION OF REMOTE SENSING

PYQ *IFoS 2025 4(a): classify RS by platform, energy source, EM-spectrum regions & number of bands. | IFoS 2016 4(a): classify by type of data acquisition.*

Remote sensing can be classified on four principal bases — source of energy, platform, region of the electromagnetic spectrum used, and number of spectral bands recorded.

2.1 BASED ON SOURCE OF ENERGY

PYQ *IFoS 2020 1(d), UK·PSC 2015: active vs passive remote sensing.*

Basis	Passive Remote Sensing	Active Remote Sensing
Energy source	Uses natural energy — mainly reflected sunlight or emitted thermal energy	Sensor generates and emits its own energy, then records the return signal
Dependence on Sun	Works only when the source (Sun) illuminates the target (mostly daytime)	Independent of the Sun; can operate day or night
Weather/cloud	Affected by cloud and atmospheric conditions (optical)	Microwave/radar can penetrate cloud, haze and operate all-weather
Examples	Optical & thermal cameras/scanners, the human eye, LANDSAT MSS/TM	RADAR, LiDAR, SONAR, SLAR



2.2 BASED ON PLATFORM

PYQ *HP·PSC 2021: ground observation vs airborne observation platform.*

- **Ground-borne (ground-based) platforms** : Sensors mounted on the Earth's surface, e.g., hand-held radiometers, towers, cranes, vehicles. Used for calibration and detailed local study.
- **Airborne (aerial) platforms** : Aircraft, helicopters, balloons and drones (UAVs). The most common method for large-scale aerial photography; flexible timing and high resolution but limited area per sortie.
- **Spaceborne (satellite) platforms** : Sensors on satellites (e.g., LANDSAT, IRS series, Sentinel). Provide repetitive, synoptic, large-area coverage at fixed orbital schedules.

2.3 BASED ON REGION OF THE ELECTROMAGNETIC SPECTRUM

- **Optical remote sensing** : Uses visible and reflected near-infrared (0.4–3.0 µm).

© Hornbill Classes
+91 78802-71423 Hornbillclasses@gmail.com

- **Infrared (IR) remote sensing** : Uses reflected and emitted infrared bands.
- **Thermal remote sensing** : Records emitted thermal infrared (3–14 µm); senses surface temperature, useful for forest fire and crop-stress detection.
- **Microwave remote sensing** : Uses microwave region (1 mm–1 m); includes passive radiometers and active radar; cloud-penetrating, all-weather.
- **LiDAR** : Active optical (laser) sensing; gives precise elevation/canopy structure.
- **SONAR** : Uses sound waves; for underwater/bathymetric sensing.

2.4 BASED ON NUMBER OF BANDS

Type	Description
Panchromatic	Records energy in a single broad band (usually 0.4–0.7 µm). Produces a single grey-scale image with high spatial detail.
Multispectral	Records energy simultaneously in a few (typically 3–10) relatively broad bands across optical, IR, thermal regions — improves spectral discrimination.
Hyperspectral	Records energy in dozens to hundreds of very narrow (as little as 0.01 µm), contiguous bands — gives a near-continuous spectrum for each pixel, enabling fine material identification.
Superspectral	Intermediate — more and narrower bands than multispectral but fewer than hyperspectral.

2.5 BASED ON TYPE OF DATA ACQUISITION

PYQ *IFoS 2016 4(a): classify RS based on type of data acquisition.*

On the basis of how data are acquired, remote sensing is classified into **passive** (recording naturally available reflected/emitted energy) and **active** (recording energy generated and transmitted by the sensor itself) — as detailed in section 2.1. This is the most fundamental data-acquisition classification.

3. ELECTROMAGNETIC RADIATION & ENERGY INTERACTIONS

Electromagnetic radiation (EMR) is the energy that carries information in remote sensing. It travels as a wave at the speed of light and is described by its **wavelength (λ)** and **frequency (ν)**, related by $c = \lambda\nu$ ($c = 3 \times 10^8$ m/s). Energy is directly proportional to frequency ($E = h\nu$) and inversely proportional to wavelength.

3.1 PROPERTIES OF EMR

- **Wavelength (λ) :** Distance between two successive wave crests; measured in micrometres (µm) or nanometres (nm).
- **Frequency (ν) :** Number of wave crests passing a fixed point per unit time; measured in hertz (Hz).
- **Amplitude :** Height of the wave — relates to the energy/intensity.
- Shorter wavelength → higher frequency → higher energy (and vice-versa).

3.2 THE ELECTROMAGNETIC SPECTRUM

The electromagnetic spectrum is the orderly arrangement of EMR by wavelength/frequency. The principal regions used in remote sensing are the visible, infrared and microwave regions.

Region	Approx. wavelength	Remote-sensing relevance
Cosmic / Gamma rays	$< 10^{-4}$ µm	Not used (absorbed by atmosphere)
X-rays	$10^{-4} – 10^{-2}$ µm	Not used in RS
Ultraviolet (UV)	10^{-2} – 0.4 µm	Limited; mineral fluorescence
Visible	0.4 – 0.7 µm	Blue, Green, Red — core optical RS

Near & Mid Infrared (NIR/MIR)	0.7 – 3.0 µm	Vegetation vigour, moisture, geology
Thermal Infrared	3 – 14 µm	Surface temperature, fire, crop stress
Microwave	1 mm – 1 m	Radar, all-weather, soil moisture
Radio waves	> 1 m	Not used in conventional RS

NEAR-INFRARED (NIR) VS MIDDLE-INFRARED (MIR)

PYQ *HP·PSC 2021: NIR vs MIR region.*

Basis	Near-Infrared (NIR)	Middle-Infrared (MIR)
Wavelength	≈ 0.7 – 1.3 µm	≈ 1.3 – 3.0 µm
Dominant response	Strongly reflected by healthy green vegetation (leaf mesophyll)	Strongly absorbed by water; sensitive to leaf & soil moisture
Main use	Vegetation vigour, biomass, NDVI	Plant/soil moisture, mineral & rock discrimination

3.3 INTERACTION OF EMR WITH THE ATMOSPHERE

PYQ *IFoS 2020 4(c): interaction of EMR with atmosphere & Earth's surface. | IFoS 2024 1(e): absorption vs scattering.*

As EMR passes through the atmosphere it is modified by three processes — **scattering, absorption and transmission**.

(a) Scattering

Scattering is the redirection (diffusion) of EMR by particles and gas molecules in the atmosphere, without a change in wavelength. It reduces image contrast. Three types are recognised:

- **Rayleigh scattering** : Caused by particles much smaller than the wavelength (gas molecules). Inversely proportional to λ^4, so it affects shorter wavelengths most (it is why the sky appears blue). Dominant in the upper atmosphere.
- **Mie scattering** : Caused by particles roughly equal in size to the wavelength (dust, smoke, pollen, water vapour). Affects longer wavelengths and is significant in the lower atmosphere, especially in overcast/hazy conditions.
- **Non-selective scattering** : Caused by particles much larger than the wavelength (water droplets, large dust). Scatters all wavelengths equally, hence clouds and fog appear white.

(b) Absorption

Absorption is the process by which atmospheric gases — chiefly **water vapour (H_2O), carbon dioxide (CO_2) and ozone (O_3)** — take up EMR energy at specific wavelengths and convert it to heat. Unlike scattering, absorption causes an actual **loss of energy** at those wavelengths (absorption bands), preventing certain wavelengths from being used for remote sensing.

Absorption vs Scattering : **Scattering redirects** energy without loss of energy and without changing wavelength (energy is diffused in different directions); **absorption removes** energy from the beam by converting it to heat at characteristic wavelengths. Scattering reduces contrast; absorption creates 'blind' wavelength bands.

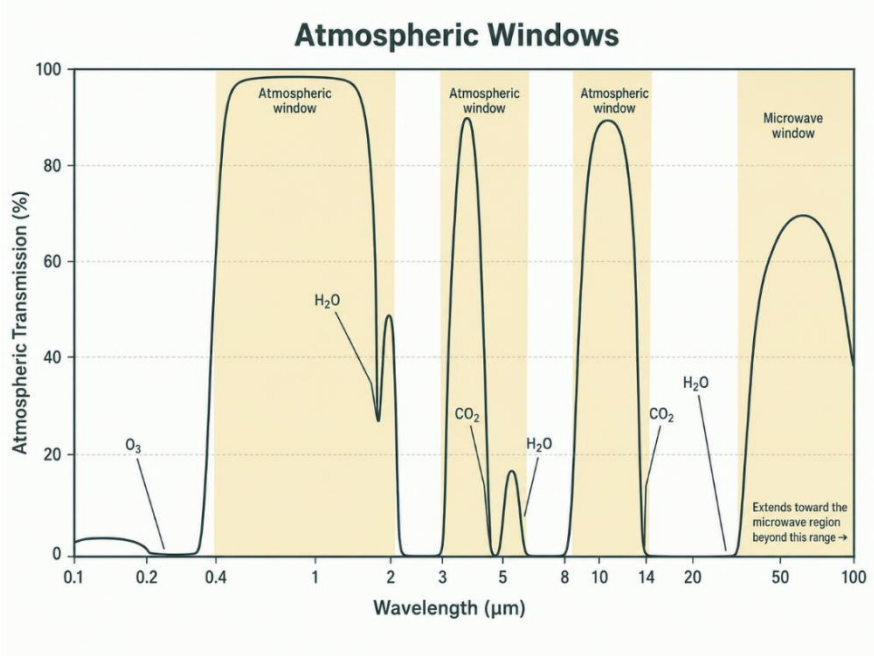
(c) Atmospheric Windows

PYQ *IFoS 2023 1(e): define atmospheric windows. | OPSC 2015: define atmospheric window.*

Those wavelength regions of the EM spectrum that are **least affected (little absorption/scattering)** by the atmosphere, and therefore transmit EMR effectively to and from the sensor, are called **atmospheric windows**.

© Hornbill Classes
+91 78802-71423 Hornbillclasses@gmail.com

Remote sensing is carried out within these windows. Examples: 0.3–0.75 µm, 1.2–1.34 µm, 3.5–4.16 µm, and the 8–14 µm thermal window, plus the microwave region (largely transparent).



3.4 INTERACTION OF EMR WITH THE EARTH'S SURFACE

When EMR strikes a surface feature, the incident energy (E_i) is partitioned into three components, following the energy-balance equation:

$$E_i(\lambda) = E_R(\lambda) + E_A(\lambda) + E_T(\lambda)$$

- **Reflection (E_R) :** energy bounced back from the surface the component most used in optical RS. Surfaces may show **specular** (mirror-like, smooth surfaces) or **diffuse/Lambertian** (rough surfaces, scattering in all directions) reflection.
- **Absorption (E_A) :** energy taken up by the feature (e.g., water absorbs NIR strongly).
- **Transmission (E_T) :** energy passing through the feature (e.g., clear water transmits visible light).

The **proportion** of energy reflected, absorbed and transmitted varies with the **material (its composition, moisture, roughness)** and with the **wavelength** of the incident energy. This wavelength-dependent reflectance is the basis of the spectral signature, and ultimately of all feature identification in remote sensing.

Key terms

PYQ *HP·PSC 2021: diffraction, Mie scattering, irradiance.*

- **Irradiance:** the amount of radiant energy incident on a surface per unit area per unit time (W/m^2). (Radiance is the energy leaving a surface per unit area per solid angle.)
- **Diffraction:** the bending/spreading of EM waves as they pass an edge or aperture; it sets the ultimate resolving limit of an optical sensor.
- **Mie scattering:** scattering by particles comparable in size to the wavelength (see 3.3a).

4. SPECTRAL REFLECTANCE & SIGNATURES

PYQ *IFoS 2020 4(a): spectral reflectance curve (soil, water, vegetation) with sketch. | OPSC 2015 & UK·PSC 2015: spectral reflectance curves using IRS bands.*

A **spectral signature** is the characteristic pattern of reflectance of a feature as a function of wavelength. A graph of percentage reflectance (Y-axis) against wavelength (X-axis) is the **spectral reflectance curve**. Because each material reflects differently across wavelengths, these curves allow features to be identified and discriminated.

VEGETATION

- **Visible (0.4–0.7 µm):** low reflectance; chlorophyll absorbs strongly in blue (0.45 µm) and red (0.67 µm), reflecting relatively more in green (0.55 µm) — hence healthy vegetation appears green.
- **Near-infrared (0.7–1.3 µm):** very high reflectance (40–50%) due to the internal leaf (mesophyll) structure — the 'red edge' rise. Healthy, vigorous vegetation reflects strongly here; stressed vegetation reflects less, the basis of crop-stress and vigour monitoring (NDVI).
- **Mid-infrared (1.3–2.5 µm):** reflectance falls at water-absorption bands (≈1.4, 1.9, 2.7 µm); sensitive to leaf moisture content.

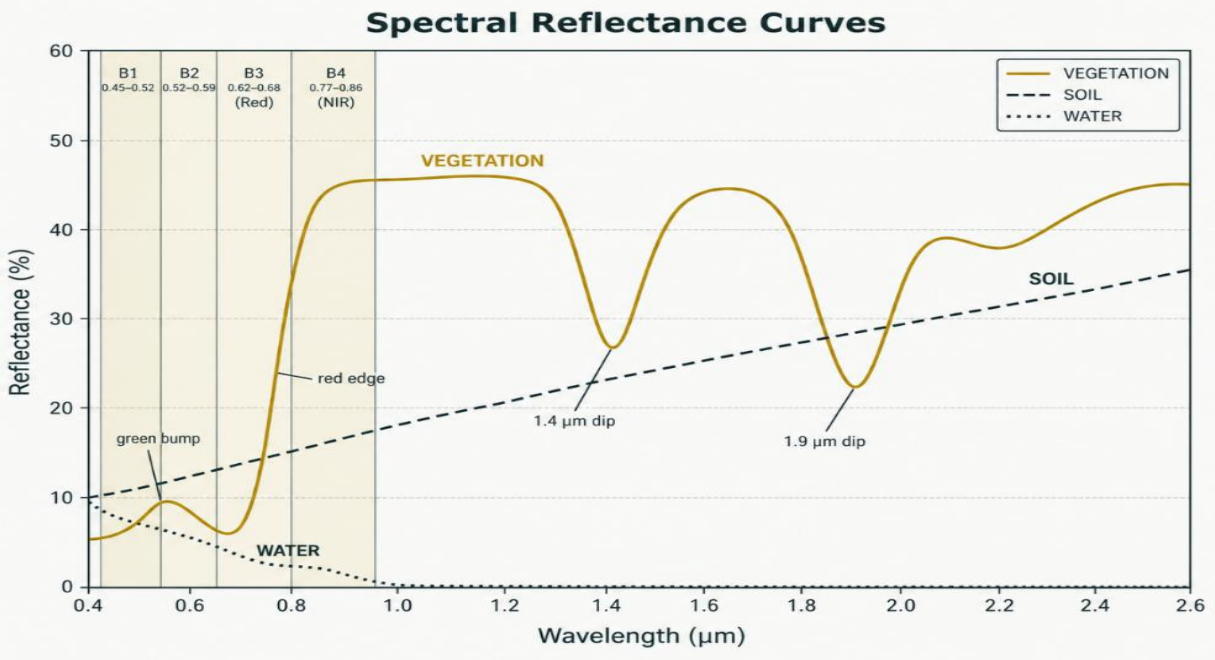
SOIL

- Comparatively **smooth, gradually rising** reflectance curve that increases with wavelength.
- Reflectance is governed by moisture content (wet soil = darker/lower reflectance), organic matter, texture, iron-oxide content and surface roughness.

WATER

- **Low overall reflectance**; reflects a little in blue–green, and **absorbs almost completely in the NIR and beyond** — hence clear water appears dark/black in NIR imagery (a key to delineating water bodies and drainage).
- Turbidity and chlorophyll/sediment raise reflectance in the visible region.

IRS bands — On Indian Remote Sensing (IRS) imagery the curves are read across the LISS bands: **Band 1 (Blue-Green 0.45–0.52), Band 2 (Green 0.52–0.59), Band 3 (Red 0.62–0.68) and Band 4 (NIR 0.77–0.86)**. The crossover where vegetation shoots above soil and water (in Band 4 / NIR) is the most diagnostic part of the graph.



© Hornbill Classes
+91 78802-71423
Hornbillclasses@gmail.com

5. RESOLUTION IN REMOTE SENSING

PYQ *IFoS 2021 4(a): importance of spatial, spectral & temporal resolution. | UK·PSC 2025 & HP·PSC 2021: types/significance of resolution.*

Resolution is the ability of a remote-sensing system to record and distinguish detail. Four types are recognised.

Type	Definition	Importance
Spatial resolution	Size of the smallest object (ground area) that can be distinguished — i.e., the ground dimension of one pixel (e.g., 5.8 m, 23.5 m, 1 km).	Determines level of detail; fine spatial resolution detects small features (individual trees, field boundaries) but covers less area.
Spectral resolution	Number and width of wavelength bands a sensor records; narrower & more bands = finer spectral resolution.	Governs the ability to discriminate materials with similar appearance (e.g., tree species, crop types, minerals).
Temporal resolution	Time interval between successive acquisitions of the same area (revisit period, e.g., 16 days, 5 days).	Critical for change detection and monitoring of dynamic phenomena (crop growth, floods, fires, deforestation).
Radiometric resolution	Sensitivity to differences in energy — number of brightness levels recorded (bits per pixel, e.g., 8-bit = 256 levels).	Determines the ability to detect subtle differences in reflectance/temperature.

Trade-off — There is an inherent trade-off: increasing spatial resolution usually reduces swath/coverage, and increasing spectral or radiometric resolution increases data volume. Sensor design balances these for the intended application.

6. SATELLITES, ORBITS & PLATFORMS

6.1 SATELLITE ORBITAL CHARACTERISTICS

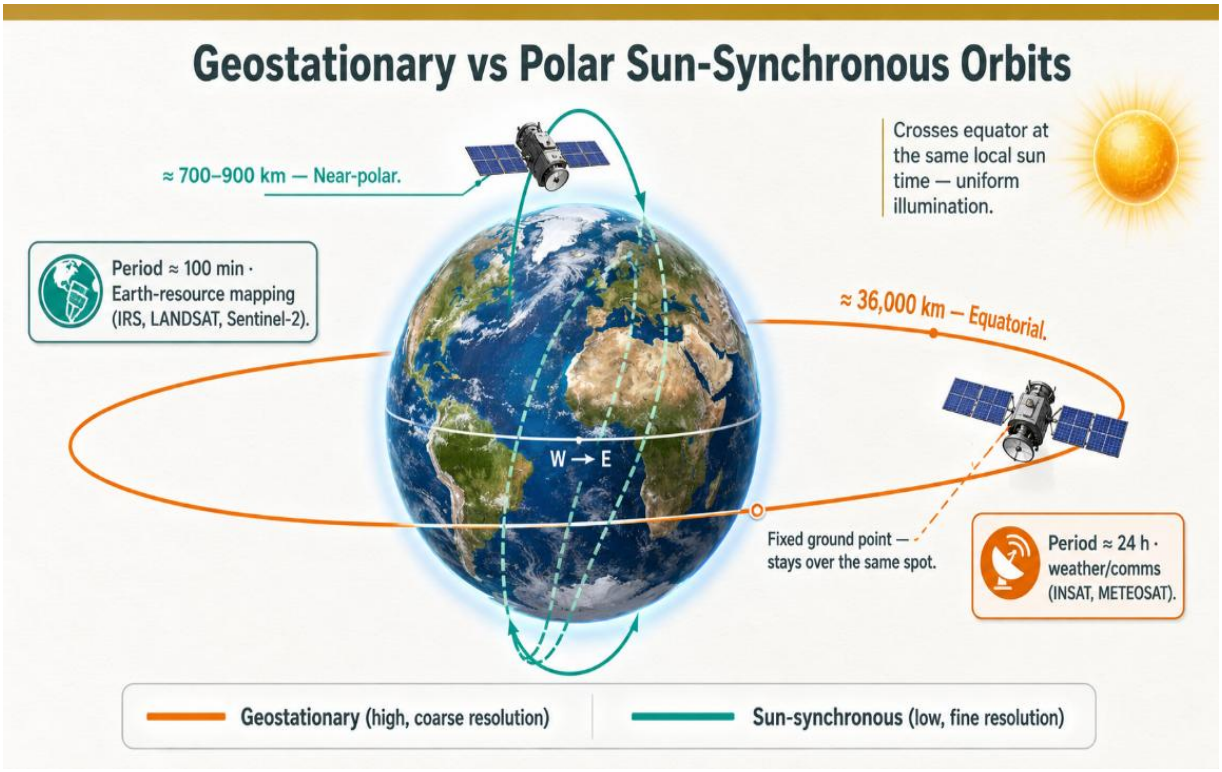
PYQ *IFoS 2020 1(e): define various satellite orbital characteristics.*

- **Altitude:** height of the satellite above the Earth's surface (e.g., ~700–900 km for sun-synchronous, ~36,000 km for geostationary).
- **Inclination angle:** angle between the orbital plane and the equatorial plane (near 0° = equatorial; near 90° = polar).
- **Period:** time taken to complete one orbit around the Earth.
- **Repeat (revisit) cycle:** number of days after which the satellite images the same area under the same conditions.
- **Swath:** width of the ground strip imaged in one pass.
- **Equatorial crossing time:** local solar time at which the satellite crosses the equator (fixed for sun-synchronous orbits to ensure constant illumination).
- **Nodes:** points where the orbit crosses the equator — descending node (N→S) and ascending node (S→N).

6.2 GEOSTATIONARY VS POLAR SUN-SYNCHRONOUS SATELLITES

PYQ *IFoS 2020 1(d): geostationary vs polar sun-synchronous. | HP·PSC 2021: geosynchronous vs sun-synchronous orbit.*

Basis	Geostationary Satellite	Polar Sun-Synchronous Satellite
Altitude	≈ 36,000 km (high)	≈ 700–900 km (low)
Orbit plane	Equatorial; moves W→E with Earth's rotation	Near-polar; passes close to both poles
Period	24 h — appears stationary over a fixed point	≈ 100 min; many orbits per day
Coverage	Continuously views the same large hemisphere/disc	Covers the whole globe strip-by-strip over its repeat cycle
Illumination	Variable	Crosses equator at the same local sun time — uniform illumination
Resolution	Coarse (very high altitude)	Fine (low altitude)
Use & examples	Communication & weather — INSAT, Kalpana, METEOSAT, GOES	Earth-resource & mapping — IRS, LANDSAT, Sentinel-2, SPOT



6.3 LANDSAT

PYQ *IFoS 2022 1(d): what do you understand by the word LANDSAT?*

LANDSAT (from 'LAND SATELLITE') is a series of American (NASA/USGS) Earth-resource remote-sensing satellites — the first civilian programme dedicated to land observation, launched from 1972 (originally ERTS-1). LANDSAT satellites occupy near-polar sun-synchronous orbits (~705–900 km) and carry multispectral sensors (MSS, TM, ETM+, OLI). The programme provides one of the longest continuous records of the Earth's land surface and is widely used for land use/land cover, forestry, agriculture and change-detection studies.

6.4 NASA (EARTH-RESOURCE) SATELLITES VS GEOSTATIONARY WEATHER SATELLITES

PYQ *IFoS 2022 4(b): differences between NASA satellite pictures and geostationary weather satellite pictures.*

© Hornbill Classes
+91 78802-71423 Hornbillclasses@gmail.com

Basis	NASA Earth-Resource Satellite (e.g., LANDSAT)	Geostationary Weather Satellite (e.g., GOES/INSAT)
Orbit	Low, near-polar, sun-synchronous (~700–900 km)	High equatorial geostationary (~36,000 km)
Spatial resolution	Fine (tens of metres) — detailed land features	Coarse (km-scale) — broad cloud/weather patterns
Temporal coverage	Repeat after days (e.g., 16 days); not continuous	Continuous, near-real-time imaging of same area (every few minutes)
Coverage area	Narrow swath strip of land	Whole hemisphere/disc
Primary purpose	Land-resource mapping & monitoring	Weather, cloud, cyclone & storm tracking

7. AERIAL PHOTOGRAPHY

Aerial photography is the technique of taking photographs of the Earth's surface from an elevated platform (aircraft, balloon, drone) using a camera with the optical axis usually pointing vertically downward. It is the oldest form of remote sensing and the basis of photogrammetry and photo-interpretation.

7.1 SENSORS / CAMERAS — TYPES

PYQ *IFoS 2025 4(c)(iii): types of cameras for aerial photography. | OPSC 2023: equipment for interpretation.*

By the EMR region used

- **Visible region :** conventional **framing (metric) camera**, **panoramic camera**.
- **Infrared region :** optical-mechanical **scanner**.
- **Microwave region : SLAR** — Side-Looking Airborne Radar.

By design / construction of the aerial camera

- **Single-lens frame camera** : the standard mapping/metric camera; captures the whole frame at one instant; used for vertical photography and photogrammetry.
- **Multi-lens camera** : several lenses expose simultaneously in different bands/angles.
- **Strip camera** : continuous strip exposure as the aircraft moves.
- **Panoramic camera** : scans a wide angle across the flight line, covering a very large field of view.
- **Digital aerial camera** : modern CCD/CMOS sensor replacing film; direct digital output.

Lens — angular coverage

- Narrow-angle (< 60°), Normal-angle (60°–75°), Wide-angle (75°–100°), Super-wide-angle (> 100°).

7.2 CLASSIFICATION OF AERIAL PHOTOGRAPHS

Basis	Types
Film used	Black-and-white (panchromatic), Infrared, Colour, False-colour (colour-IR)
Camera/device	Single-lens, Double-lens, Multiple-lens photography
Scale	Large scale (1:5,000–1:20,000); Medium (1:20,000–1:40,000); Small (1:40,000–1:70,000)

Optical axis of camera	Vertical photographs (axis ≈ vertical); Oblique photographs (axis tilted) — further: low oblique (no horizon) & high oblique (horizon visible)

Vertical vs Oblique Photographs

Vertical Photograph	Oblique Photograph
Optical axis vertical (≤ 3° tilt)	Optical axis deliberately tilted
Can be used directly as a map	Cannot be used as a map
Covers the least area	Covers a larger area
Scale nearly uniform throughout	Scale varies across the photo
Coverage is rectangular	Coverage is trapezoidal
Suitable for any terrain & mapping	Not suitable for hilly/precise mapping

7.3 AERIAL PHOTOGRAPH VS MAP

PYQ *IFoS 2000: differences between aerial photography and maps.*

Aerial Photograph (perspective projection)	Map (orthographic projection)
Shows the actual image of objects	Shows objects by conventional symbols
Scale varies with terrain & place to place	Scale is constant
Records all ground objects, wanted or not	Shows only the desired/selected objects
Produced quickly	Requires long time after fieldwork
Provides a 3-D (stereo) view	Provides a 2-D view only
Does not directly record height, contours, spot levels	Can show heights, contours and other annotated data

7.4 PHOTOGRAPHIC SCALE & FLYING HEIGHT

Photographic scale is the ratio of a distance on the photograph to the corresponding distance on the ground, expressed as 1:20,000 or as the representative fraction. For a vertical photo over flat terrain:

Scale = f / (H – h) where f = focal length, H = flying height above datum, h = ground elevation of the terrain.

- Scale **increases** as flying height is reduced (ground comes closer to the camera) and **decreases** as flying height increases.
- For the **same flying height**, a change in ground elevation changes the photo scale — higher ground (smaller H–h) gives a larger scale.

Factors affecting choice of scale

- Purpose/object for which the photograph is to be used; Topography of the area; Type of camera and its focal length available; Cruising height of the survey aircraft; Season of photography.

7.5 SEASON OF PHOTOGRAPHY (INDIAN CONTEXT)

PYQ *IFoS 2022 1(d): seasonal influences on images.*

India's wide variation in physiography and climate (and its many forest types) makes the **choice of season critical** for cloud-free, leaf-condition-appropriate imagery:

- Most trees in tropical India **shed leaves in summer (after March)**, hampering species identification.
- **April–June:** North India suffers haze, dust, smoke and forest fires.

© Hornbill Classes
+91 78802-71423 Hornbillclasses@gmail.com

- **Monsoon:** heavy cloud cover prevents satellite imaging over most of the country; Tamil Nadu is then clearer, but the NE monsoon (Oct–Dec) clouds TN.
- **Himalaya:** snow cover Dec–March/April.

Best season — Most suitable: **October to February** (except hill regions); for large areas the best window is **October–November**. (Forest-type specific: Himalayan conifers Oct–Nov; deciduous Dec–Feb; Sal — N. India mid-March to mid-April; Teak — N. India Sep–Dec; tropical evergreen Jan–Feb.)

8. PHOTOGRAMMETRY & STEREOSCOPY

Photogrammetry is the art and science of obtaining reliable measurements and information about physical objects and the terrain (e.g., tree height, crown diameter, tree volume, crown density, areas and elevations) through measurements made on aerial photographs.

8.1 STEREOSCOPY & PARALLAX

- **Stereoscopy** is the science of perceiving depth (3-D) by viewing two overlapping photographs (a **stereo pair**) of the same area taken from two different camera positions, through a **stereoscope**.
- **Stereo pair / overlap:** successive vertical photos along a flight line have ~60% forward overlap, providing the two views needed for 3-D.
- **Parallax (image parallax):** the apparent displacement of the position of an object, relative to a reference, caused by a change in the point of observation. **Differential parallax** between the top and base of an object is used to compute its height.
- **Air base (B):** the ground distance between the two camera exposure stations of a stereo pair.

8.2 VERTICAL EXAGGERATION (VE)

PYQ *IFoS 2022 4(c): vertical exaggeration numerical.*

When a stereo pair is viewed, the perceived **vertical scale is larger than the horizontal scale**, so relief (heights and slopes) appears exaggerated. This **vertical exaggeration** actually aids interpretation of low-relief features but must be allowed for when judging slopes. A commonly used approximation is:

$$VE = (B / H) \times (h / e) = (B \times h) / (H \times e)$$

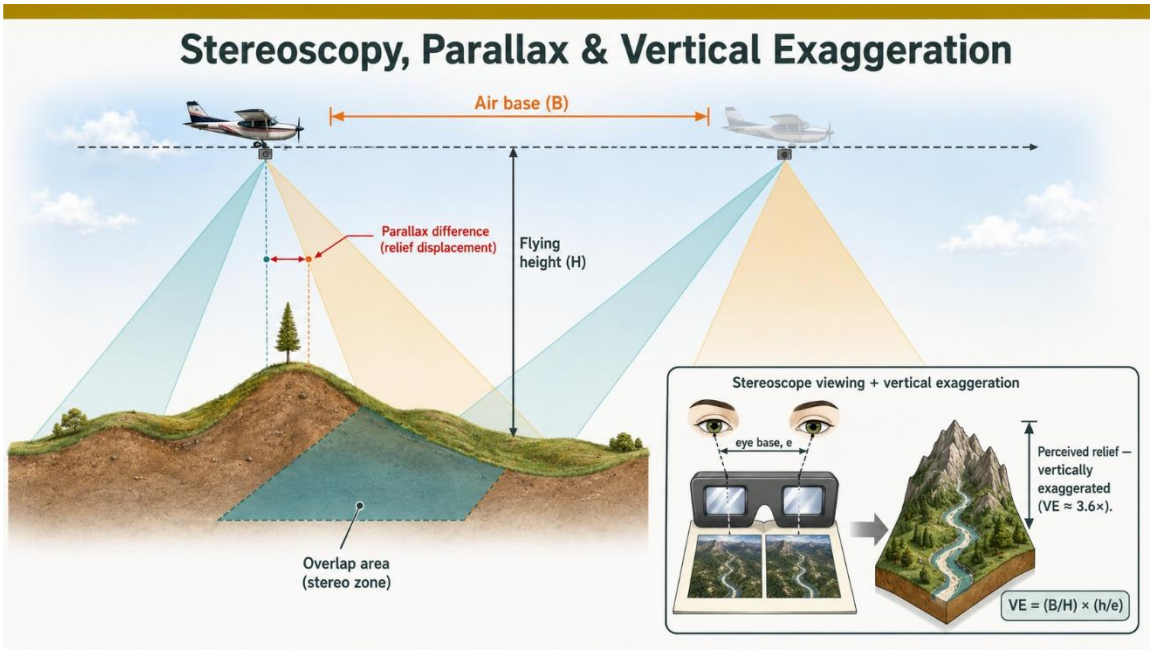
where B = air base, H = flying height above the terrain, h = apparent stereoscopic viewing distance, e = eye base (interpupillary distance of the viewer). The ratio B/H is the **base–height ratio**.

Worked example (IFoS 2022)

Given: air base B = 2000 m; height of camera above terrain H = 4000 m; viewing distance h = 50 cm; eye base e = 7 cm.

- Base–height ratio B/H = 2000 / 4000 = **0.5**
- Viewing ratio h/e = 50 / 7 = **7.14**
- **VE = 0.5 × 7.14 ≈ 3.57 ≈ 3.6**

Interpretation — A VE of about **3.6 means the vertical scale appears roughly 3.6 times the horizontal scale** — slopes and heights look about 3.6× steeper than they really are. This strong exaggeration makes subtle relief and drainage easy to perceive in stereo, but slope angles read off the model must be corrected (true slope is much gentler than it appears).



8.3 MEASUREMENT FROM PHOTOGRAPHS

Tree height

- **Relief-displacement (parallax) method:** relief displacement on a vertical photo is directly proportional to object height. Requirements: the tree is vertical, sufficient relief displacement is measurable, and both the top and base of the tree are visible.
- **Shadow method:** height is estimated from shadow length and the sun's elevation angle. Requires: known sun angle at the time of photography, the photo scale at the place of the shadow, a long, clear, unobstructed shadow and level ground; not possible in dense forest.

Crown diameter

- **Dot-/crown-gauge (wedge) method:** crown diameter is measured by adjusting a calibrated gauge (graduated dots/wedge) against the crown image until it just matches.

9. PHOTOGRAMMETRY & STEREOSCOPY

Photo (image) interpretation is the act of examining photographic/satellite images and judging their significance — i.e., identifying objects and features (such as a tree species) and assessing their meaning. It relies on a set of recognition keys (elements).

9.1 ELEMENTS / KEYS OF IMAGE INTERPRETATION

PYQ *IFoS 2023 4(a): basic keys & sequence of image interpretation. | IFoS 2022 4(a) (20M): elements of air-photo interpretation. | UK·PSC 2025, MH·PSC 2024.*

Element	Meaning / use in identification
Tone (colour)	Relative brightness/shade from white to black (or hue in colour photos), caused by differential reflection. The most basic element; affected by light angle.
Shape	External form/outline (e.g., conifers = conical crown; babool = broad crown). Man-made features show regular geometric shapes.
Size	Relative or absolute dimensions (crown size, height); helps separate similar shapes.

© Hornbill Classes
+91 78802-71423 Hornbillclasses@gmail.com

Shadow	Profile/outline cast by an object; aids crown-shape and height judgement; depends on sun angle and time of photography.
Texture	Frequency of tonal change and arrangement of tones — smooth (young/uniform crop) vs coarse (old/mixed forest).
Pattern	Spatial arrangement of objects — linear/regular = plantation; irregular = natural forest; drainage patterns indicate geology.
Site / Location	Topographic position (hill vs valley, ridge, floodplain) that constrains what a feature can be.
Association	Occurrence of related features together — identifying one feature helps identify associated ones.

9.2 ORDERING OF ELEMENTS BY DEGREE OF COMPLEXITY

PYQ *IFoS 2021 1(e): ordering of each element of photo-interpretation by degree of complexity.*

Interpretation elements are used in a progressive order, from simple to complex:

- **Primary (first-order) — directly recorded :** tone/colour. The most basic element, read directly from brightness.
- **Secondary (spatial arrangement of tone):** size, shape, texture, pattern — derived from the geometric/spatial arrangement of tones.
- **Tertiary (positional/contextual) :** site/location, association, shadow — require reasoning about position and relationships.
- **Highest order (inferential) :** convergence of evidence — combining several elements to reach a conclusion (e.g., resolution and ground-related properties).

9.3 FACTORS INFLUENCING INTERPRETATION

PYQ *IFoS 2022 4(a): factors that influence interpretation of RS images.*

- Quality of the imagery — scale, spatial/spectral resolution, season and sun angle.
- Film/band combination used (panchromatic, colour, false-colour IR).
- Stereoscopic vs monoscopic viewing; quality of viewing equipment.
- Skill, training and local field knowledge of the interpreter.
- Availability of collateral data and ground truth.

9.4 SEQUENCE OF THE INTERPRETATION PROCESS

PYQ *IFoS 2023 4(a): sequence followed in image interpretation. | UK·PSC 2012: interpretation for NRM.*

1. **Detection** : locating/distinguishing the presence of an object or feature.
2. **Recognition & identification** : naming the object using the interpretation keys.
3. **Analysis** : delineating boundaries of like features (grouping).
4. **Deduction / classification** : inferring identity using convergence of evidence.
5. **Classification & idealisation** : assigning features to classes and drawing the final interpreted map.
6. **Verification (ground truthing)** : checking interpreted results against the ground.

9.5 EQUIPMENT FOR PHOTO INTERPRETATION

PYQ *OPSC Forest 2023: equipment for interpretation of photographic images.*

- **Stereoscopes** : pocket (lens) stereoscope and mirror stereoscope, for 3-D viewing of stereo pairs.

- **Parallax bar (stereometer)** : for measuring differential parallax (heights).
- **Magnifiers / light tables / scanners**, and digital workstations for on-screen interpretation.

10. DIGITAL IMAGE PROCESSING (DIP)

A digital image is a 2-D array of **pixels**, each carrying a brightness value (digital number, DN). **Digital image processing** is the use of computer algorithms to correct, enhance, transform and classify these digital numbers so as to extract meaningful information. DIP is the single most-examined theme of this chapter.

10.1 ADVANTAGES OF DIGITAL IMAGE PROCESSING

PYQ *IFoS 2024 4(b): advantages of DIP. | IFoS 2019 2(c): computer-assisted operations.*

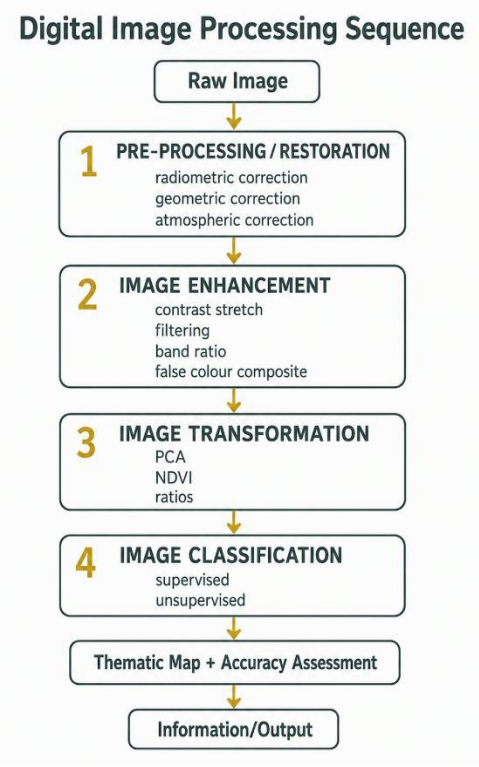
- Permits **correction** of geometric and radiometric errors objectively and repeatably.
- Enables powerful **enhancement** (contrast stretch, filtering, ratios) to reveal subtle features.
- Allows **quantitative, automated classification** of large data sets — faster and more consistent than visual methods.
- Supports **multi-temporal/multi-sensor integration** and easy GIS linkage.
- Data can be reproduced, stored and shared without degradation.

10.2 DIGITAL IMAGE PROCESSING SEQUENCE

PYQ *IFoS 2021 4(b): DIP sequence with flowchart. | IFoS 2020 4(b): methods of DIP. | IFoS 2019 2(c): types of computer-assisted operations.*

DIP proceeds through four broad stages (computer-assisted operations):

1. **Image Pre-processing / Restoration** — correcting sensor, geometric and atmospheric distortions to restore the image to its true form (radiometric & geometric correction).
2. **Image Enhancement** — improving visual appearance to aid interpretation (contrast stretching, density slicing, spatial filtering, band ratioing, FCC).
3. **Image Transformation** — combining/manipulating bands to derive new images (Principal Component Analysis, vegetation indices like NDVI, ratios).
4. **Image Classification & Analysis** — assigning pixels to thematic classes (supervised/unsupervised) to produce a thematic map; followed by accuracy assessment.



10.3 IMAGE RESTORATION

PYQ *IFoS 2023 1(d): process of restoration.*

Restoration (pre-processing) aims to compensate for, or remove, distortions and degradations introduced during data acquisition so that the image more faithfully represents the original scene. It includes removal of sensor noise and striping/line-drop, and the two key corrections below — radiometric and geometric correction.

10.4 RADIOMETRIC CORRECTION

PYQ *IFoS 2024 3(c): radiometric correction.*

© Hornbill Classes
+91 78802-71423 Hornbillclasses@gmail.com

Radiometric correction rectifies errors in the **brightness (DN) values** of pixels caused by sensor response variations, atmospheric scattering/absorption and illumination (sun-angle) differences. It restores the true radiance/reflectance of features. Operations include sensor calibration, striping/line-drop correction, atmospheric correction (haze removal) and sun-angle/topographic correction.

10.5 GEOMETRIC CORRECTION

PYQ *IFoS 2024 3(c) & 2023 1(d): geometric correction.*

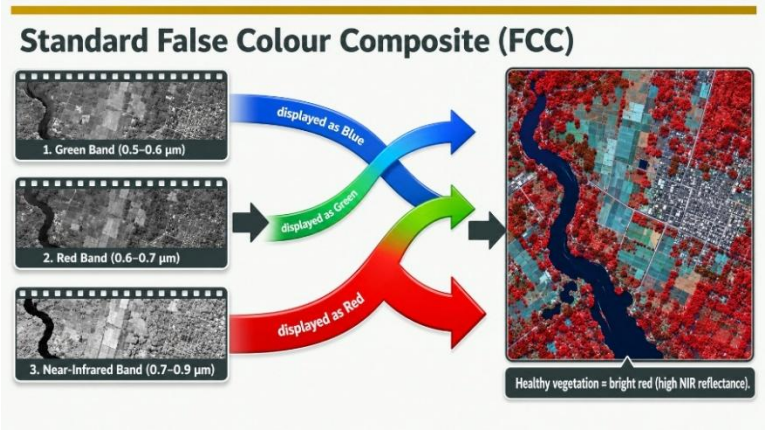
Geometric correction removes **positional/geometric distortions** so that image pixels correspond to true ground coordinates (a map projection). Distortions arise from Earth curvature and rotation, platform altitude/attitude variations, sensor scanning and relief. Steps:

1. Select **Ground Control Points (GCPs)** — features identifiable on both image and map/reference.
2. Fit a **coordinate transformation** (polynomial) relating image to map coordinates.
3. **Resampling** (nearest-neighbour, bilinear, cubic convolution) to assign DN values to the corrected grid.

> **Radiometric vs Geometric — Radiometric correction fixes the pixel's value (brightness); geometric correction fixes the pixel's position (location).** Restoration encompasses both, plus noise removal.

10.6 IMAGE ENHANCEMENT & FALSE COLOUR COMPOSITE

PYQ *IFoS 2023 1(e): what is false colour composite?*



- **Contrast stretching, density slicing, spatial filtering and band ratioing** improve the visual separability of features.
- **False Colour Composite (FCC):** a colour image created by assigning the three additive primaries (Blue, Green, Red display channels) to bands **other** than their natural ones — classically the **green band → blue, red band → green, and near-infrared band → red**. Because healthy vegetation reflects strongly in NIR, it appears in **bright red** on a standard FCC, making vegetation mapping and vigour assessment easy. (A 'true colour composite' instead assigns each band to its natural colour.)

10.7 IMAGE CLASSIFICATION

PYQ *IFoS 2023 4(b): how is classification done in DIP? | IFoS 2020 4(b): methods of DIP, discuss one.*

Classification assigns every pixel to a thematic class (e.g., water, forest, crop, built-up) based on its spectral (DN) values, converting a multispectral image into a thematic map. Two approaches:

Supervised Classification	Unsupervised Classification
Analyst defines 'training sites' of known classes	Algorithm groups pixels with no prior training
Software computes class signatures from training data	Pixels clustered by natural spectral groupings
Pixels assigned by rules — Minimum-Distance, Parallelepiped, Maximum-Likelihood	Clustering algorithms — ISODATA, K-means

Classes are known & labelled in advance	Clusters are labelled by the analyst afterwards
Needs good ground knowledge; more accurate	Less analyst input; clusters may not match real classes

Maximum-Likelihood (a supervised method) — in detail: it assumes the DN values of each class are normally distributed and computes, for each pixel, the statistical probability of belonging to each class; the pixel is assigned to the class of highest probability. It is the most widely used and generally most accurate per-pixel classifier, though computationally heavier.

10.8 PRINCIPAL COMPONENT ANALYSIS (PCA)

PYQ *IFoS 2024 4(b): significance of principal component analysis in DIP.*

Adjacent bands of multispectral data are often highly **correlated** (redundant). **Principal Component Analysis** is a statistical transformation that rotates the data axes to produce a new set of **uncorrelated bands (principal components, PCs)**, ordered so that PC-1 carries the maximum variance, PC-2 the next, and so on.

Significance / advantages

- **Reduces data redundancy and dimensionality** — most information is compressed into the first few PCs, reducing storage and processing.
- Removes inter-band correlation; later PCs often isolate **noise**, aiding noise removal.
- **Enhances features** and subtle information not visible in the original bands; useful for change detection and FCC generation from PCs.

10.9 REMOTE SENSING DATA PRODUCTS

PYQ *IFoS 2025 4(c)(i): remote sensing data products.*

Data products are the processed forms in which remote-sensing data are supplied to users:

- **Photographic (analogue) products** — film/paper prints (B&W, FCC).
- **Digital products** — data on media/online as raw or geocoded pixel arrays (e.g., GeoTIFF).
- By **correction level:** raw (Level 0), radiometrically corrected (standard), geo-referenced/geo-coded (precision), and value-added/derived products (mosaics, NDVI maps, DEMs, thematic maps).
- Products are characterised by their spatial, spectral, radiometric and temporal resolution and by path/row referencing.

10.10 GROUND TRUTHING

PYQ *IFoS 2025 4(b): importance & requirement of ground truthing; parameters for land-cover types.*

Ground truthing (ground verification) is the collection of reference information directly in the field, at or near the time of overpass, to **train, calibrate and validate** the interpretation of remote-sensing data.

Importance / requirement

- Provides **training data** for supervised classification and reference for assigning spectral classes to real ground features.
- Enables **accuracy assessment** of the classified map.
- Helps **calibrate sensors** and correct atmospheric effects, linking image DN values to actual surface conditions.
- Resolves ambiguities where different features have similar spectral responses.

Parameters of ground truthing for land-cover types

© Hornbill Classes
+91 78802-71423 Hornbillclasses@gmail.com

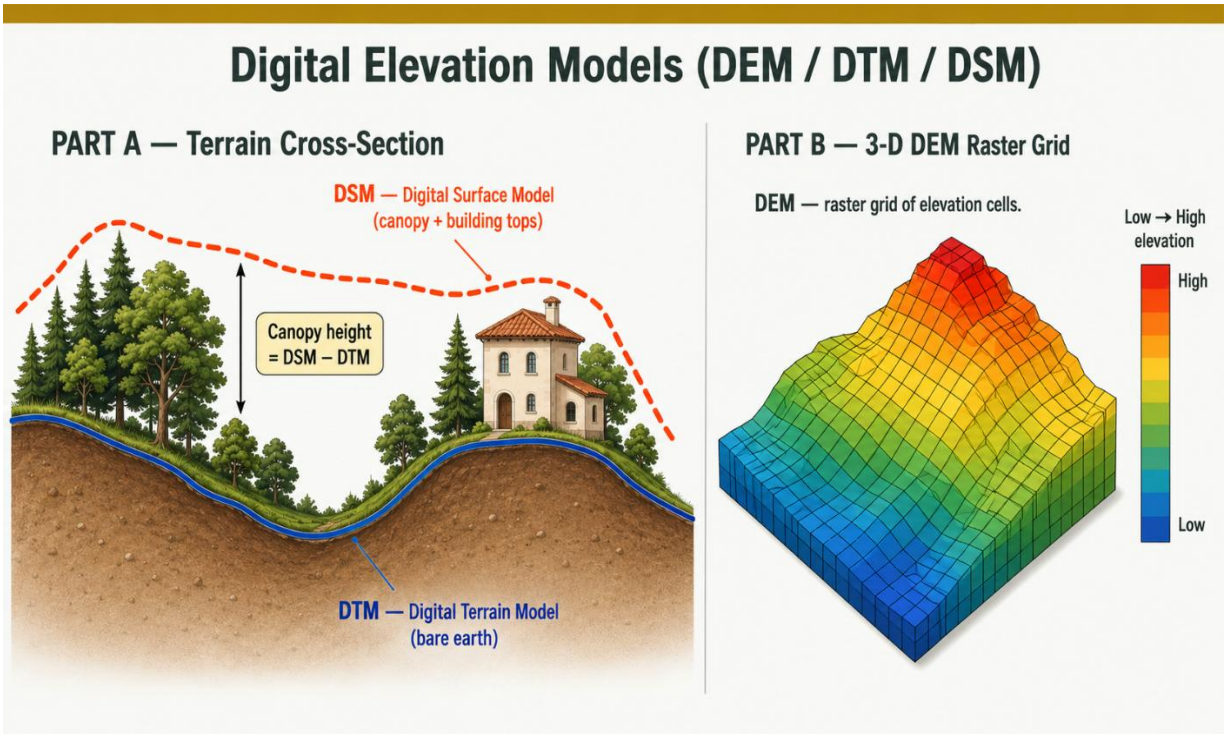
- **Location** — accurate GPS coordinates of each sample/observation site.
- **Land-cover/land-use type** — class label (forest, crop, water, built-up, fallow, etc.).
- **Vegetation parameters** — species, crown cover/canopy density, height, growth stage/phenology, biomass.
- **Soil parameters** — type, colour, texture, surface moisture.
- **Surface condition & date/time** — moisture, roughness, illumination and the acquisition date (to match the overpass).
- **Supporting records** — field photographs, spectral (radiometer) readings where available.

11. DIGITAL ELEVATION MODELS (DEM)

PYQ *IFoS 2025 4(c)(ii): digital elevation models.*

A **Digital Elevation Model (DEM)** is a digital, raster representation of the terrain surface — a grid of cells each storing the **elevation** of the ground at that location. It is the basis for analysing topography.

- **DTM (Digital Terrain Model)** — elevation of the **bare ground** surface (vegetation/buildings removed).
- **DSM (Digital Surface Model)** — elevation of the **top surface** including tree canopy, buildings, etc.
- **Sources:** stereo-photogrammetry (overlapping photos/satellite stereo), interferometric radar (InSAR, e.g., SRTM), and LiDAR (highest accuracy).
- **Uses:** slope, aspect and contour generation; watershed and drainage delineation; flood and landslide modelling; line-of-sight & viewshed analysis; orthophoto generation; forest canopy height (DSM − DTM).



12. APPLICATIONS OF REMOTE SENSING

PYQ *IFoS 2016 4(a): RS in agriculture & forestry. | 2024 4(a): LULC. | 2019 1(c): water resources. | 2022 1(e): archaeology. | 2025 4(c): forest cover & crop water-stress.*

12.1 AGRICULTURE

- **Crop identification & acreage estimation** — discriminating crop types and mapping extent using multi-temporal multispectral data.
- **Crop condition & yield forecasting** — vegetation indices (NDVI) track vigour; early warning of pest/disease and weather anomalies; production estimation for food security.
- **Agricultural drought monitoring** and soil/water resource assessment.
- **Precision farming** — site-specific application of seed, water, fertiliser and pesticide using RS + GPS + GIS, improving productivity and cutting input waste (e.g., crop-residue burning monitoring in Punjab).

Crop Water-Stress Monitoring

PYQ *IFoS 2025 4(c)(v): application of RS for crop water-stress monitoring.*

Water-stressed crops change spectral and thermal behaviour: as stomata close, **canopy temperature rises** (less evaporative cooling) and **NIR reflectance falls** while shortwave-IR (moisture-sensitive) reflectance rises. RS detects stress by:

- **Thermal infrared sensing** — raised canopy temperature relative to air temperature signals stress; basis of the **Crop Water Stress Index (CWSI)**.
- **Optical/NIR & SWIR indices** — NDVI, NDWI and moisture indices reveal declining vigour and leaf water content before visible wilting.
- Enables **timely irrigation scheduling**, drought early-warning and efficient water use over large areas.

12.2 FORESTRY

(The institute's forestry applications, retained in full, with an agricultural-engineering emphasis where relevant.)

- **Forest cover & area mapping / change detection** — Forest Survey of India (FSI) carries out **biennial** forest-cover assessment using satellite data, tracking deforestation, afforestation and degradation.
- **Forest type & species classification, stand-structure mapping**, and estimation of **growing stock and biomass/carbon** for working plans and inventory.
- **Forest fire monitoring** — FSI's Forest Fire Alert System (FAST) uses **MODIS (1 km)** and **SNPP-VIIRS (375 m)** thermal data to detect and disseminate fire hotspots in near-real time.
- **Thermal remote sensing** specifically aids fire detection, surface-temperature/heat-stress mapping and detection of diseased/stressed stands.
- **Monitoring invasive species** (Parthenium, Lantana, water hyacinth) via distinct phenology and spectral response using multi/hyperspectral data.
- **Wildlife habitat** — habitat pattern, fragmentation and corridor analysis.
- **Forest hydrology & watershed management, wetland dynamics, carbon-cycle and landscape/ecosystem modelling.**

Forest Cover Mapping using Remote Sensing

PYQ *IFoS 2025 4(c)(iv): forest cover mapping using remote sensing.*

Forest cover mapping exploits the strong **NIR reflectance of healthy canopy** (high NDVI) to separate forest from non-forest, then classifies **canopy-density classes** (very dense > 70%, moderately dense 40-70%, open 10-40%). Repetitive satellite coverage allows **change detection** between dates; in India FSI maps national forest cover biennially from IRS/Resourcesat data for the State of Forest Report.

12.3 LAND USE / LAND COVER (LULC) MAPPING

PYQ *IFoS 2024 4(a): RS in land cover & land use mapping. | UK·PSC 2021.*

© Hornbill Classes
+91 78802-71423 Hornbillclasses@gmail.com

- **Land cover** = physical material on the surface (forest, water, soil, built-up); **land use** = human function of that land (agriculture, residential, recreation).
- Both are delineated from the **spectral signatures** of features on multispectral imagery; colour and false-colour imagery and stereo viewing improve identification.
- **Multi-temporal** RS enables LULC **change detection** — urban expansion, deforestation, cropping change — vital for planning and resource management.

12.4 WATER RESOURCES

PYQ *IFoS 2019 1(c): RS in water resources studies.*

- Mapping and monitoring **surface water bodie** — rivers, lakes, reservoirs, wetlands — and their seasonal change (water is dark in NIR, easy to delineate).
- **Snow-cover and glacier mapping** for snowmelt-runoff estimation in Himalayan catchments.
- **Groundwater prospect mapping** via lithology, lineaments and geomorphology.
- **Flood mapping & damage assessment** (microwave/radar penetrates monsoon cloud).
- Watershed delineation, soil-moisture and reservoir-sedimentation studies, and water-quality (turbidity, algal bloom) monitoring.

12.5 ARCHAEOLOGY

PYQ *IFoS 2022 1(e): RS / image interpretation in archaeological investigation, with example.*

Buried or surface archaeological remains often produce subtle differences in **soil tone, moisture, vegetation vigour (crop marks) and micro-relief** imperceptible on the ground but visible from above — especially in oblique light, infrared and thermal imagery.

- **Crop / soil marks:** crops over buried walls grow poorly (stunted) while those over buried ditches grow more vigorously, creating tonal patterns on photos.
- **Thermal & multispectral imagery** reveals sub-surface features through temperature/moisture contrasts.
- **Example:** aerial/satellite imagery has traced the buried palaeo-channel of the **Saraswati (Ghaggar-Hakra)** river and associated Harappan sites in NW India; internationally, crop-mark detection of buried Roman remains.

12. KEY DEFINITIONS (GLOSSARY)

PYQ *OPSC Forest 2015 2(d): define resolution, topology, geodesy, sensor, atmospheric window, swath width, image parallax. | HP·PSC 2021.*

Term	Definition
Resolution	Ability of a sensor to record and distinguish detail — spatial, spectral, radiometric and temporal (see Section 5).
Sensor	Device that detects and records electromagnetic radiation reflected or emitted from a target (camera, scanner, radiometer, radar).
Atmospheric window	Wavelength region least affected by atmospheric absorption/scattering, through which EMR is transmitted effectively for sensing.
Swath width	Width of the ground strip imaged by a sensor in a single pass (field of view projected on the ground).
Image parallax	Apparent displacement of an object's image position caused by a change in observation point; differential parallax gives object height.

Topology	In GIS, the spatial relationships (connectivity, adjacency, containment) between features, independent of their coordinates.
Geodesy	Science of measuring and representing the size, shape, gravity field and orientation of the Earth and positions on it.
Irradiance	Radiant energy incident on a surface per unit area per unit time (W/m2).
Nadir	Point on the ground vertically beneath the sensor; the swath is centred on the nadir track.

© Hornbill Classes
+91 78802-71423 Hornbillclasses@gmail.com

CHAPTER

6

GIS APPLICATIONS

GIS Fundamentals · Components · Raster & Vector Data · Spatial Analysis · RS–GIS–GPS Integration · Geoinformatics · Watershed · Water · Land · Forest Management · FIS

OFFICIAL SYLLABUS — *Chapter 6 scope*

Geographic Information System (GIS) — principles, data types (raster and vector formats). Spatial analysis, attribute data and GIS software. Integration of remote sensing and GIS in land and water management, watershed development and prioritization, forest management, water resources, and other agricultural-engineering applications.

Chapter Outline

1 Introduction To Gis
2 Components Of Gis
3 Gis, Remote Sensing & Gps — The Geospatial Trinity
4 Spatial Data Models — Gis Data Types
5 Data Layers, Spatial Analysis & Gis Functions
6 Remote Sensing – Gis Integration
7 Geoinformatics, Giscience & Geomatics
8 Applications Of Gis & Rs–Gis Integration
9 Forest Information Systems (Fis / Nfis)
10 Advantages & Limitations Of Gis

1. INTRODUCTION TO GIS

PYQ *IFoS 2018 2(a), 2017 4(a): what is GIS? | OPSC Forest 2015, UK·PSC 2012: explain GIS.*

A **Geographic Information System (GIS)** is a computer-based information system used to capture, store, retrieve, manipulate, analyse and display **geospatial (geographically referenced) data** in order to support decision-making for the planning and management of land, water, natural resources and the environment.

Geospatial / spatial data describe the location (where) and the attributes (what) of features on the Earth's surface — features that can be located by a geographic coordinate system (latitude/longitude or projected coordinates). GIS is what links the **'where' (spatial/location) to the 'what' (attribute/descriptive)** information.

Two senses of GIS — As a **system**, GIS is the integration of hardware, software, data, people and methods. As a **science** (GIScience), it is the body of concepts and techniques — spatial analysis, modelling, visualisation algorithms — underlying those systems. This dual nature is why GIS is treated as a combination of science and technology.

2. COMPONENTS OF GIS

PYQ *OPSC Forest 2015 4(d): the five components of GIS.*

A functioning GIS is built from **five essential components**:



1. **Hardware** — the physical equipment on which GIS runs: computer/CPU, monitor, storage, and peripherals such as digitizer, scanner, GPS, plotter and printer.
2. **Software** — the GIS program that provides the tools and functions to input, store, query, analyse and display geographic information (e.g., ArcGIS, QGIS).
3. **Data** — the most important and most expensive component: spatial data (maps, satellite imagery, aerial photographs) plus their linked attribute (tabular) data; collected in-house or bought.
4. **People / Users** — the trained personnel, from technical specialists who design and maintain the system to the end users who apply it in their everyday work; without people the system has limited value.
5. **Methods / Procedures** — the well-designed plans, rules and workflows (models, standards, operating procedures) according to which the GIS is implemented for each organisation.

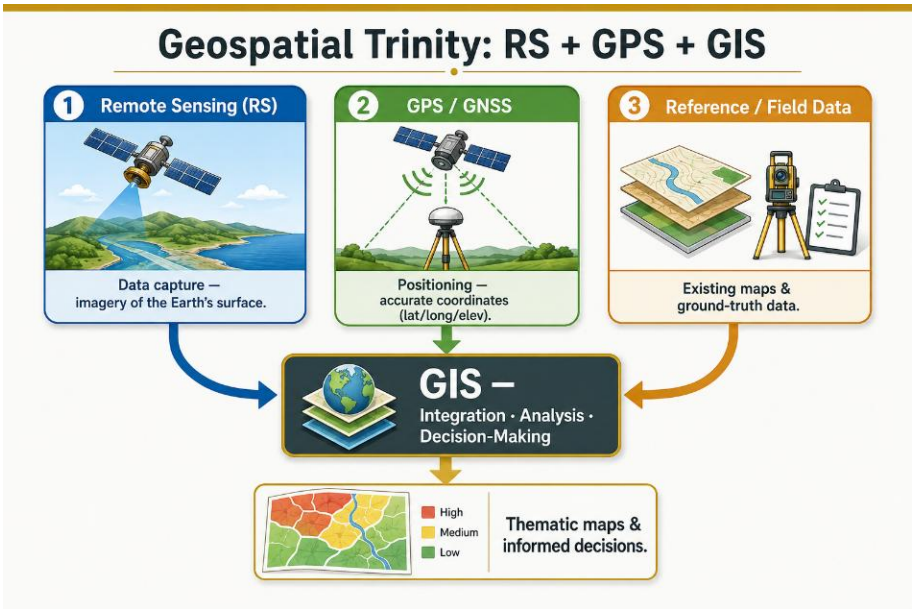
3. GIS, REMOTE SENSING & GPS — THE GEOSPATIAL TRINITY

Geospatial technology rests on three complementary technologies that are frequently integrated:

Technology	Primary role
Remote Sensing (RS)	Data acquisition — captures information about the Earth's surface from sensors on satellites/aircraft (the source of spatial data).
GPS / GNSS	Positioning — provides accurate ground location (coordinates) of features and ground-control/ground-truth points.
GIS	Data management & analysis — stores, integrates, analyses and presents spatial data from RS, GPS and other sources for decision-making.

© Hornbill Classes
+91 78802-71423 Hornbillclasses@gmail.com

3.1 GPS / GNSS (IN BRIEF)



The **Global Positioning System (GPS)** — and the broader family of **Global Navigation Satellite Systems (GNSS)** — uses a constellation of satellites to determine the precise position (latitude, longitude, elevation) of a receiver on the Earth by measuring distances to four or more satellites (trilateration). India's regional system is **NavIC (IRNSS)**. In the geospatial workflow, GPS supplies accurate coordinates for **ground truthing, georeferencing of imagery, field-data collection and laying out features** mapped in GIS.

4. SPATIAL DATA MODELS — GIS DATA TYPES

PYQ *IFoS 2021 1(d): GIS data types. | IFoS 2021 1(c)(i): how does raster differ from vector format?*

GIS data are of two broad kinds: **spatial data** (location/geometry of features) and **attribute (non-spatial) data** (the descriptive characteristics of those features, held in tables and linked to the geometry). Spatial data are represented by **two data models — raster and vector**.

4.1 RASTER DATA MODEL

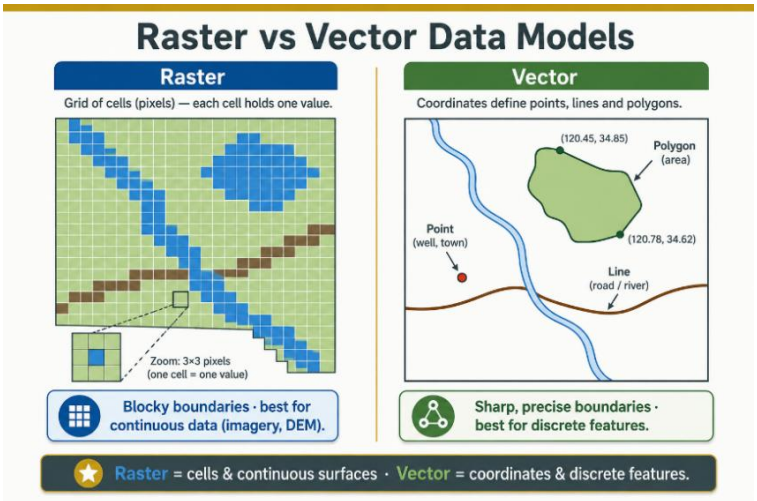
- Represents space as a **grid of cells (pixels)**, each cell holding a single value for the attribute (e.g., elevation, land-cover class, temperature).
- Location is given implicitly by the cell's row/column position; **resolution = cell size** (smaller cell = finer detail, larger file).
- Best for **continuous/surface data** — satellite imagery, DEMs, rainfall, temperature, slope.
- Simple structure, fast overlay/map-algebra; but large data volume and 'blocky' (stair-stepped) boundaries.

4.2 VECTOR DATA MODEL

- Represents features by **coordinate geometry** using three primitives: **points** (wells, towns — 0-D), **lines/arcs** (roads, rivers, contours — 1-D) and **polygons** (forest stands, watersheds, fields — 2-D).
- Location is stored explicitly as (x, y) coordinates; **topology** records spatial relationships (connectivity, adjacency, containment).
- Best for **discrete features with definite boundaries** — cadastral maps, drainage networks, administrative boundaries.
- Compact, accurate boundaries, good for network analysis; but overlay of many layers is computationally heavier.

4.3 RASTER VS VECTOR — COMPARISON

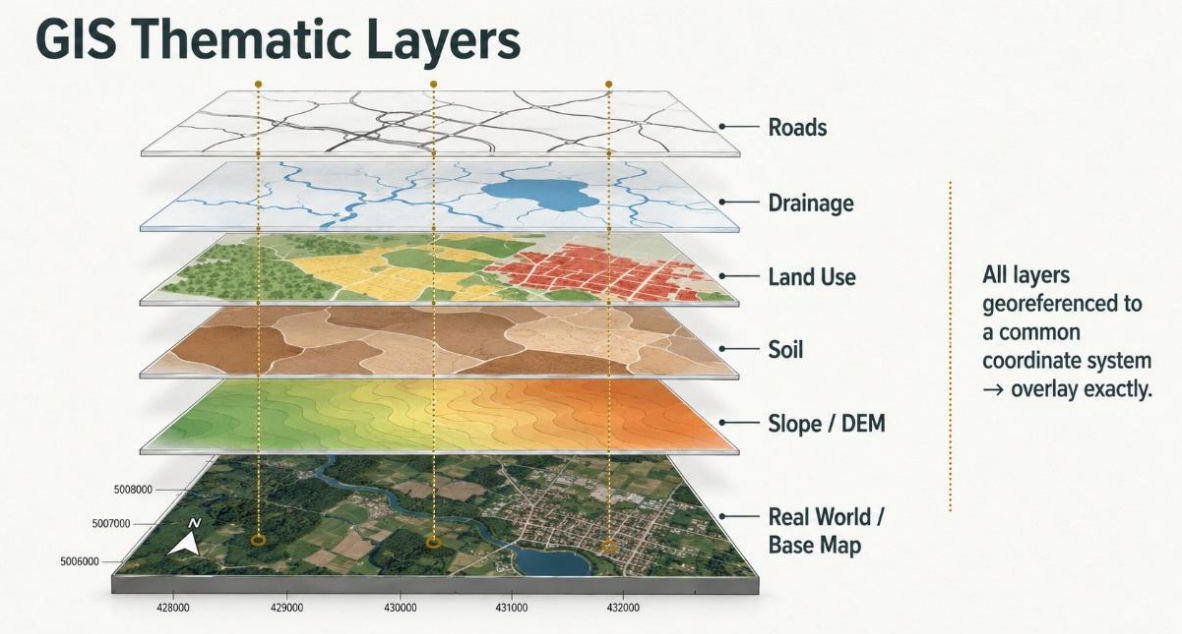
Basis	Raster	Vector
Structure	Grid of cells (pixels)	Points, lines, polygons (coordinates)
Location	Implicit (row/column)	Explicit (x, y coordinates)
Best for	Continuous data (imagery, DEM, slope)	Discrete features (roads, parcels, boundaries)
Boundaries	Blocky / stair-stepped	Sharp and precise
Data volume	Large (esp. fine resolution)	Compact
Topology	Not inherent	Explicitly stored
Analysis strength	Map algebra, overlay, surface analysis	Network analysis, precise area/length, queries
Output quality	Lower cartographic quality	High-quality, scalable maps



5. DATA LAYERS, SPATIAL ANALYSIS & GIS FUNCTIONS

5.1 CONCEPT OF LAYERS (THEMES)

In GIS the real world is broken into a set of thematic layers (themes) — e.g., drainage, roads, soil, land use, slope, geology — all georeferenced to a common coordinate system so they overlay exactly. Analysis comes from combining these layers. This layered, georeferenced structure is the central principle of GIS.



© Hornbill Classes
+91 78802-71423 Hornbillclasses@gmail.com

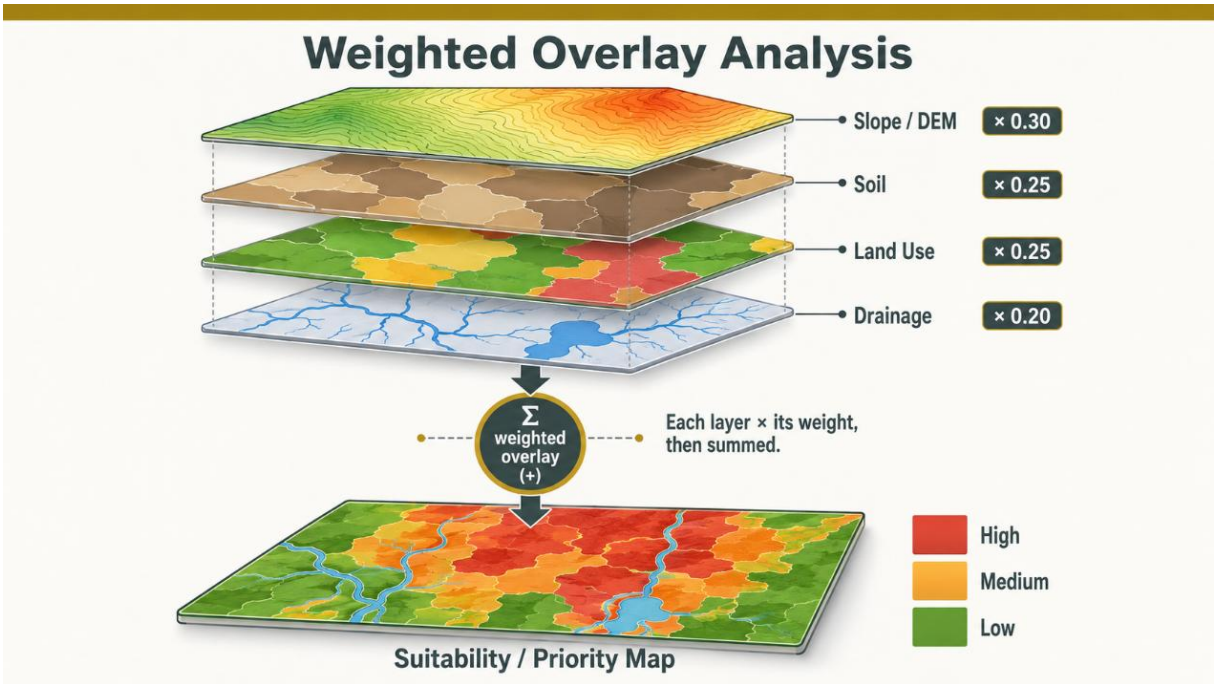
5.2 FUNCTIONS OF GIS

A GIS performs four core groups of functions, which also describe the **principles of its operation**:

1. **Data input / capture** — digitizing maps, importing RS imagery, GPS surveys, scanning, and attaching attribute tables.
2. **Data storage & management** — organising spatial and attribute data in a geodatabase (with topology).
3. **Data analysis / manipulation** — the analytical heart of GIS (see spatial analysis below).
4. **Data output / display** — maps, reports, charts and 3-D views for the user.

5.3 SPATIAL ANALYSIS — KEY OPERATIONS

- **Overlay analysis** — superimposing layers (union, intersect) to find where conditions coincide; weighted overlay combines layers by assigned weights — the basis of suitability and prioritization maps.
- **Buffer analysis** — creating zones of a given distance around features (e.g., 100 m buffer along a stream, settlement proximity).
- **Query / retrieval** — selecting features by attribute (e.g., 'all forest > 70% canopy') or by location.
- **Proximity & network analysis** — nearest facility, shortest path, drainage networks.
- **Interpolation & surface analysis** — generating continuous surfaces (rainfall, slope, aspect) and deriving terrain parameters from a DEM.
- **Spatial statistics & modelling** — density, change detection, predictive modelling.



6. REMOTE SENSING – GIS INTEGRATION

PYQ *IFoS 2017 4(a): principles of GIS & RS and applications. | OPSC Forest 2023/19: merits of conventional vs RS + GIS use.*

RS and GIS are **complementary**: remote sensing is the most efficient **source of timely, repetitive, large-area spatial data**, while GIS is the system that **stores, integrates and analyses** that data together with other layers (soil, terrain, socio-economic). Integration means RS-derived thematic layers (land use, NDVI, water bodies) become inputs to GIS overlay and modelling, and GIS in turn helps in classifying and interpreting RS data.

Why integrate — RS alone gives the picture; GIS alone needs data. Together they enable **multi-criteria decision-making** — e.g., overlaying RS land-use with soil, slope and drainage layers to prioritise watersheds, site conservation structures, or map fire-risk zones.

6.1 GIS SOFTWARE

Common GIS/image-processing packages: **ArcGIS, QGIS (open-source), ERDAS Imagine, ENVI, IDRISI/TerrSet, ILWIS, GRASS, SAGA**. Indian platforms include ISRO's **Bhuvan** geoportal and NRSC data products.

7. GEOINFORMATICS, GISCIENCE & GEOMATICS

PYQ *IFoS 2021: define geoinformatics, its elements & role in forest monitoring. | IFoS 2020: why GIS as a 'pure science'?*

These overlapping terms describe the wider field around GIS:

- **GIScience (Geographic Information Science)** — the **science** underlying GIS: the theory, concepts, analysis and visualisation techniques and algorithms for handling geographic data. It is not application-specific. Because it has its own body of principles, methods and research questions, GIS is regarded as a science ('pure'/geospatial information science), not merely a software tool.
- **Geoinformatics** — the science and technology that develops and uses information-science infrastructure to address problems in the geosciences; the fusion of geosciences and informatics. Its four main tasks: (1) collection & processing of geodata, (2) development & management of geodata databases, (3) analysis & modelling of geodata, (4) development & integration of the software/logic for these tasks. Its core **elements/technologies are Remote Sensing, GIS and GNSS (GeoComputation).**
- **Geomatics** — the broader discipline of gathering, storing, processing and delivering spatially-referenced information; it integrates geodesy, surveying, GNSS, cartography, remote sensing, photogrammetry and GIS, and additionally emphasises traditional surveying and mapping. Geoinformatics is a subset of geomatics.

Exam framing — For 'Why is GIS a pure science?' — argue that GIScience has its own concepts, principles, analytical methods and research base (spatial analysis, data modelling, error/uncertainty, visualisation), independent of any single application. For 'geoinformatics elements' — list RS, GIS and GNSS plus the four data tasks above.

8. APPLICATIONS OF GIS & RS–GIS INTEGRATION

8.1 WATERSHED DEVELOPMENT, MANAGEMENT & PRIORITIZATION

PYQ *IFoS 2017 4(a). | OPSC·CSE 2016-2024 (×5), UK·PSC 2012, OPSC Forest 2023: role of RS & GIS in watershed planning, development, prioritization & SWC decision-making.*

A **watershed** (the area draining to a common outlet) is the natural unit for soil-and-water-conservation planning. RS and GIS together provide the spatial database and analytical engine for the whole watershed cycle — investigation, planning, prioritization, implementation and evaluation.

Role in watershed planning & development

- **Resource inventory (from RS):** land use/land cover, drainage network, slope/relief (from DEM), soil, geology, geomorphology, lineaments and existing water bodies are mapped as **thematic layers**.

© Hornbill Classes
+91 78802-71423 Hornbillclasses@gmail.com

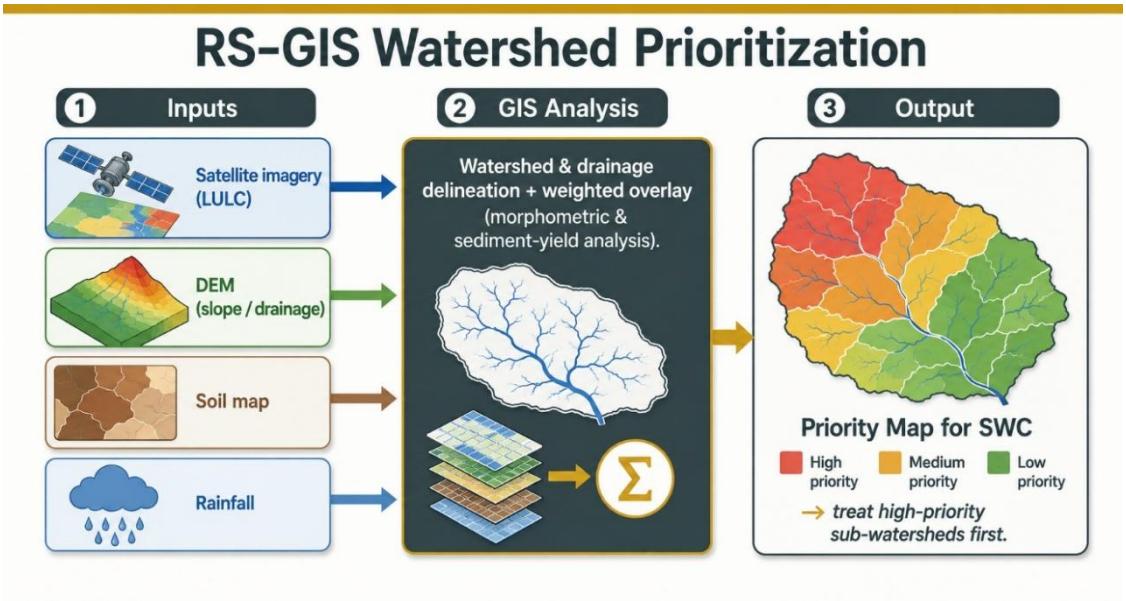
- **Drainage & morphometric analysis (GIS):** delineation of watershed/sub-watershed boundaries and drainage from the DEM; computation of morphometric parameters (drainage density, bifurcation ratio, relief, form factor) that indicate runoff and erosion behaviour.
- **Integrated overlay analysis:** weighted overlay of thematic layers identifies suitable sites for conservation/water-harvesting structures (check dams, percolation tanks, farm ponds, contour bunds) and zones for afforestation, agriculture or recharge.
- **Action / development plan:** generation of a composite land-and-water resource development plan and recommended treatments for each land parcel.

Watershed prioritization (which watershed to treat first)

Because funds are limited, watersheds/sub-watersheds are **ranked** so the most critical are treated first. RS-GIS enables prioritization by:

- **Sediment Yield Index (SYI) / erosion-based prioritization** — combining erosion-intensity (from LULC, slope and soil) with silt-yield potential to rank sub-watersheds by soil-loss risk.
- **Morphometric prioritization** — ranking sub-watersheds using compound values of morphometric parameters (drainage density, drainage texture, form factor, etc.).
- **Multi-criteria weighted overlay** — slope, soil erodibility, LULC, rainfall and drainage combined to produce High–Medium–Low priority maps.

Decision-making for SWC — By overlaying RS-derived and ancillary layers, GIS turns scattered data into **actionable, location-specific decisions** — which sub-watershed to treat first, which structure to build where, and how much area needs afforestation — making soil-and-water-conservation planning objective, fast, repeatable and auditable.



8.2 WATER RESOURCE DEVELOPMENT & MANAGEMENT

PYQ *IFoS 2025 1(e): application of GIS in water resource development & management.*

- **Surface-water mapping & monitoring** — inventory of rivers, lakes, reservoirs, tanks and their seasonal/temporal change.
- **Groundwater prospect & recharge-site mapping** — overlay of geology, geomorphology, lineaments, slope and LULC to demarcate groundwater-potential zones and artificial-recharge sites.

- **Watershed-based water harvesting** — siting check dams, percolation ponds and farm ponds (see 8.1).
- **Flood & drought management** — flood-hazard zonation, inundation mapping (radar in monsoon) and drought monitoring.
- **Irrigation & command-area management** — canal network mapping, command-area performance, water-logging and salinity monitoring.
- **Reservoir sedimentation and water-quality assessment** using multi-temporal imagery.

8.3 LAND & LAND–WATER MANAGEMENT

PYQ *IFoS 2018 2(a): RS-GIS applications in land & water management*

- **Land use / land cover (LULC) mapping & planning** — base for all resource planning.
- **Land capability & suitability classification** and wasteland/degraded-land mapping for reclamation.
- **Land-degradation & soil-erosion mapping** (water/wind erosion, salinity, ravines).
- **Integrated land-and-water resource development** at watershed level (combines 8.1 & 8.2).

LULC change monitoring with RS-GIS

PYQ *UK·PSC 2021: monitor LULC change using RS & GIS.*

Land use = human function of land; **land cover** = physical surface material. Multi-date satellite imagery is classified into LULC maps for different years; GIS **change-detection overlay** (post-classification comparison) then quantifies and maps the gains/losses — urban growth, deforestation, cropping change — guiding planning and conservation.

8.4 FOREST MANAGEMENT

PYQ *IFoS 2021 4(c) (15M), 2019, 2018, 2017, 2016. | UPPSC ACF 2021: forest stock maps. | UK/HP/MP/Mizoram/HPSC: RS-GIS in forestry.*

- **Forest cover & type mapping / change detection** — FSI maps national forest cover **biennially** from satellite data (with DIP), making assessment faster and more accurate; classifies canopy-density classes and detects deforestation.
- **Forest stock / stand mapping** — RS + GIS prepare **forest stock maps** (species/type, density, growing-stock strata) by linking image-derived strata with field inventory plots in the GIS, supporting working plans and inventory.
- **Forest fire risk zonation & mapping** — overlay of fuel load, slope, aspect, altitude, drainage, and distance from roads/settlements (each weighted) yields High–Low fire-risk zones; supports FSI's early-warning, fire-danger rating and fire-line/relief planning.
- **Wildlife habitat & corridor analysis** — habitat suitability, fragmentation and migration-corridor mapping.
- **Carbon-stock assessment, afforestation monitoring** (e.g., CAMPA / Green India Mission via e-Greenwatch), and biodiversity/conservation planning.

8.5 OTHER APPLICATIONS

- **Agriculture & precision farming** — crop acreage/condition, yield forecasting, soil & input management.
- **Disaster & climate management** — hazard zonation, situational awareness and response for floods, cyclones, landslides, droughts.
- **Healthcare, logistics, transport, meteorology, marketing, real estate, insurance, ecology** — broad geospatial decision-support uses.

© Hornbill Classes
+91 78802-71423 Hornbillclasses@gmail.com

9. FOREST INFORMATION SYSTEMS (FIS / NFIS)

PYQ *Supports forest-monitoring & geoinformatics-in-forestry questions (IFoS 2021/2019).*

A **Forest Information System (FIS)** is a modern, computer-based decision-support tool that supplies decision-makers with comprehensive, integrated information for the sustainable management of forest ecosystems.

- **National Forestry Information System (NFIS)** — an open, web-based system run by the **Forest Survey of India (FSI)** that integrates satellite imagery, GIS and ground-survey data.
- Used to **monitor centrally-sponsored afforestation schemes** — Green India Mission (GIM), Compensatory Afforestation (CAMPA) and the National Afforestation Programme (NAP) — managing both spatial and non-spatial data.
- Helps **validate and disseminate forestry statistics** for national/international commitments, and compiles data on production, consumption, export and import of timber and non-timber forest products.

10. ADVANTAGES & LIMITATIONS OF GIS

10.1 ADVANTAGES

- Integrates **multi-source, multi-layer** spatial and attribute data in one georeferenced framework.
- Powerful **spatial analysis & modelling** (overlay, prioritization, suitability) for objective decision-making.
- **Rapid update, query and visualisation**; easy scenario/'what-if' analysis.
- Supports **multi-temporal change detection** and integration with RS and GPS.

10.2 LIMITATIONS

PYQ *Balances the 'merits/demerits' and critical-appraisal questions.*

- Data may **lack spatial or temporal continuity**; collection is time-consuming.
- GIS data and specialised hardware/software are **relatively expensive**.
- Output quality **depends on input data quality** — poor source maps introduce serious errors.
- **Privacy, security and misuse/misinterpretation** concerns; long learning curve.
- GIS shows **spatial relationships but does not by itself explain them** or give absolute solutions; demands knowledge of all integrated disciplines.

10.3 APPENDIX: SPECULAR VS DIFFUSE REFLECTANCE

PYQ *IFoS 2021 1(c)(ii): differentiate specular and diffusive reflectance (paired with the raster/vector question).*

Specular Reflectance	Diffuse (Diffusive) Reflectance
Occurs on smooth surfaces (relative to wavelength), e.g., calm water, glass	Occurs on rough surfaces, e.g., soil, vegetation
Mirror-like — angle of reflection = angle of incidence	Energy scattered in all directions (Lambertian)
Energy returned in one direction; can cause sun-glint	Energy returned more or less equally to all directions
Little useful information for most RS	The useful reflectance for most optical remote sensing

Congratulations

To all our successful candidates in

INDIAN FOREST SERVICE (IFOS) 2025



Siddharath

Comprehensive Interview Guidance Program (CIGP)



Karan Kumar Singh



Aanchal Sharma

Comprehensive Interview Guidance Program (CIGP)



Sankalp Dixit

Comprehensive Interview Guidance Program (CIGP)



Ravi Laxmipriya

Comprehensive Interview Guidance Program (CIGP)



Abhimanyu Balyan

Comprehensive Interview Guidance Program (CIGP)



Ravinanadan Gupta

Comprehensive Forestry Course + Test Series + CIGP



Divyanjali Jaiswal

Comprehensive Forestry Course



Abhay Raghav

Comprehensive Interview Guidance Program



Puneet Kumar

Comprehensive Forestry Course + CIGP



Kadam Sumati Yashawant

Comprehensive Forestry Course + CIGP



Aman Ayushkar

Comprehensive Interview Guidance Program (CIGP)



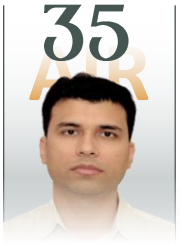
Sushmita Singh

Comprehensive Interview Guidance Program (CIGP)



Athul Ajay

Test Series



Anurag Kumar

Comprehensive Interview Guidance Program (CIGP)



Deepshikha

Comprehensive Forestry Course + CIGP



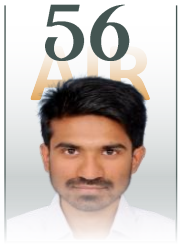
B Jaya Aswantha Reddy

Comprehensive Forestry Course 2022



Sanskar Bharti

Test Series



Sachin Datt

Test Series + CIGP



Anusha Srinivas

Comprehensive Forestry Course + Test Series



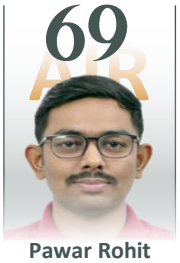
Ashish

Comprehensive Forestry Course + Test Series



Saurabh Singh

Comprehensive Forestry Course



Pawar Rohit Sanjay

Comprehensive Interview Guidance Program (CIGP)



Omkar Kumar

Comprehensive Forestry Course 2024



Manav Gupta

Comprehensive Forestry Course + CIGP



Prityesh Raj

Comprehensive Interview Guidance Program (CIGP)



Reshma Nivetha R

Comprehensive Forestry Course + CIGP



Pawar Akshay Haribhau

Comprehensive Interview Guidance Program (CIGP)



Sambhav Kumar Jain

Test Series



Rajat Kataria

Comprehensive Interview Guidance Program (CIGP)

Congratulations

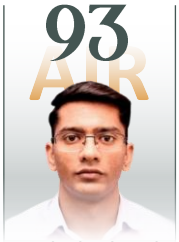
To all our successful candidates in

INDIAN FOREST SERVICE (IFOS) 2025



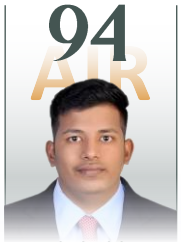
Rajat Kumar

Comprehensive Forestry Course + CIGP



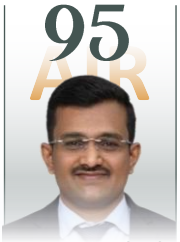
Kailash Chand Yadav

Comprehensive Forestry Course + CIGP



Patil Shubham Jaysing

Comprehensive Forestry Course



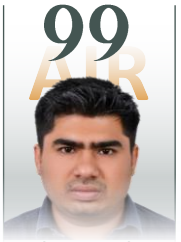
Hinge Harshad Pandurang

Comprehensive Forestry Course (2023) + Test Series + CIGP



Pawar Onkar Mahesh

Comprehensive Interview Guidance Program (CIGP)



Dharmendra Choudhary

Comprehensive Interview Guidance Program (CIGP)



Kushare Pratik Chandrashekhar

Comprehensive Interview Guidance Program (CIGP)



Venkatesh M

Comprehensive Forestry Course + CIGP



K Sai Goutham

Comprehensive Forestry Course



Kritika Negi

Comprehensive Forestry Course 2023 + CIGP 2025



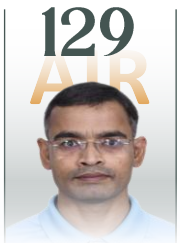
Himanshu Kumar

Comprehensive Forestry Course 2023 + CIGP



Satyam Shivam Sundaram

Comprehensive Interview Guidance Program (CIGP)



Satya Pal Arya

Comprehensive Interview Guidance Program (CIGP)



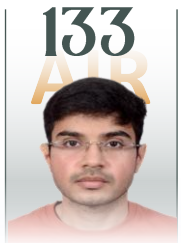
Aakash Verma

Comprehensive Forestry Course



Ajay Kumar Ushara

Comprehensive Forestry Course + CIGP



Vikalp Mandawaria

Comprehensive Forestry Course + Test Series + CIGP



Prateek Kumar Meena

Comprehensive Forestry Course + CIGP



Chinthanai Selvan T

Comprehensive Forestry Course



Naresh Mandhan

Comprehensive Forestry Course



Rajan Sharma

Comprehensive Interview Guidance Program (CIGP)

50 Out of **148** Total Selections in

Indian Forest Service (IFoS) 2025



Online / Offline Batches

Comprehensive syllabus coverage with detailed PYQ analysis

- Online / offline batches to suit your needs
- 2 years of validity with unlimited access to all resources.



Study Material

- PYQ- and syllabus-based content.
- High-quality color-printed materials with rich visual graphics.
- Fully aligned with current exam trends and requirements.



Test Series

Personalized feedback, detailed solutions, and tailored suggestions for each candidate — ensuring targeted improvement and exam success.



Leader In Forest Services

A premier institute dedicated to Forest Service examinations, offering expert guidance for IFoS, ACF, RFO, and ICFRE/ICAR–(ASRB) ARS/NET exams.